12-1-2013

New Mouthguard Design with Intermediate Nickel-Titanium and Foam Layer

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NEW MOUTHGUARD DESIGN WITH INTERMEDIATE NICKEL-TITANIUM AND FOAM LAYER

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Bachelor of Science in Biology
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2008

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University of the Pacific
2011

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science - Oral Biology

School of Dental Medicine
Division of Health Sciences
The Graduate College

University of Nevada, Las Vegas
December 2013

THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Freddie Martinez

entitled

New Mouthguard Design with Intermediate Nickel-Titanium and Foam Layer

is approved in partial fulfillment of the requirements for the degree of

Master of Science - Oral Biology

School of Dental Medicine

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December 2013

Abstract

New Mouthguard Design with Intermediate Nickel-Titanium and Foam Layer

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Mouthguards help prevent orofacial injuries in many physical activities, commonly to the maxillary incisors. Mouthguards have many different properties which can be idealized. One property involves the amount of impact force the mouthguard can dissipate, commonly referred to as shock absorption. The aim of this study was to improve shock absorption capabilities beyond the protection that a mouthguard made of Ethylene Vinyl Acetate (EVA) can offer. A Nickel-Titanium (NiTi) and/or foam intermediate layer was placed between EVA. Seven configurations were fabricated at 3 different thicknesses. The configurations consisted of an intermediate layer composed of NiTi, foam, or NiTi/foam. The NiTi strips varied in porosity: 0%, 31%, and 50%. A drop tower was used for two different test methods. In the first test method, samples were placed on a flat plate attached to a force sensor that recorded transmitted peak force. The second testing method involved a simply supported aluminum plate that allowed some deflection allowing the calculation of energy absorption using transmitted peak force and strain energy data. Configurations with a NiTi intermediate layer in the three thickness groups performed significantly worse than the control in both the flat plate test and the simply supported beam test. The configurations with foam performed significantly better in the 2mm thickness group ($P<.05$) and the 3mm thickness group ($P<.05$), but not in the 4mm thickness group ($P>.05$). Configurations with NiTi/foam did not perform significantly different from the control except for the samples in the 4mm thickness group which tested significantly worse ($P<.05$). The same configurations tested significantly better in the second test ($P<.05$), except in the 4mm Thickness group ($P>.05$). No difference was observed between the varying porosities ($P>.05$).

Acknowledgements

I would like to thank Dr. James Mah, my advisor and chair, for his guidance and support. Dr. Bob Martin and Dr. Cliff Seran were instrumental in my success during residency and I am sincerely grateful to have worked with such amazing individuals and mentors. I also want to thank Dr. Brendan O'Toole and the mechanical engineering department for embracing interdepartmental research by supporting this project with a grant, for allowing me to use their equipment and facility, and the overall support. Lastly, I want to thank Adam Kessler. This project would not have been possible without his knowledge and tremendous help.

Dedication

To my parents

Gracias por todo el amor, los animos, y apoyo que me an dado

I love you

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Chapter 1: Introduction

Background and Significance

Mouthguards have played a large role in protecting athletes from orofacial injuries in modern times. They help to reduce injuries by absorbing some of the impact and redistributing the force. The American Dental Association (ADA) recognizes the importance of wearing mouthguards and recommends their use in 29 sporting activities. Currently, many organized sports at different levels mandate the use of mouthguards. The number of injuries prevented by mouthguard wear each year is difficult to determine due to lack of data but the ADA estimates that athletes are sixty times more likely to suffer injury to teeth without one (ADA Council 2006). Often these injuries remain with the individual for the rest of their life. For example, a dental injury can require numerous visits to the dentist for treatment and follow up. Other issues include significant costs, esthetic and functional problems.

In general, there are three types of mouthguard. The most common is the mouth formed mouthguard, otherwise known as a boil and bite. This type is widely available and low cost. The athlete simply places the mouthguard in hot water and moulds it to his teeth by biting. The resulting product varies significantly and is generally not well adapted to the teeth resulting in a poor fit. This has a significantly negative effect on the mouthguard's shock absorption capability (Vieira 2008). In addition, this type of mouthguard can be very thin in critical areas such as the occlusal surface and incisal edges depending on the bite force, technique and variables such as mouthguard temperature at the time of moulding. The second type is a stock mouthguard which is the simplest of all the mouthguard options. This type is manufactured in a variety of sizes and is ready to use without further modifications. As a result, stock mouthguards have very poor fit and are the least protective of the three types (Patrick 2005). Lastly, custom made mouthguards are those fabricated by a laboratory usually through a dental office. These offer the best fit and most protection (Patrick 2005). They are fabricated in a multi-step process, by first taking an impression of the patient's teeth, gums, and vestibule, and creating a stone model of the mouth. The dental laboratory will then thermoform a specially designed mouthguard material onto the stone model. The mouthguard material is typically ethylene vinyl acetate (EVA) and is trimmed and polished to its final form.

At this time, there is no body or authority that has officially specified a particular material or method of fabrication or design. As such, many fabrication materials have been explored. EVA seems to be the most widely used material and offers a good combination of desirable properties (Going 1974). Mouthguard design features and variables include: extension into the vestibule, the posterior length, coverage of the palate and occlusion. One of the most important design variables is thickness which has a direct correlation with the amount of protection offered up to a certain thickness (Westerman 2002). Mouthguard thickness is a critical variable given the fabrication methods available today.

Custom mouthguards are often fabricated using one of two thermoforming methods. The first method is a vacuum form machine which uses suction to help adapt the heated mouthguard material around a model. This method is relatively inexpensive but difficult to operate and technique sensitive. It is difficult to produce a consistent product using a vacuum form machine. The second type is a pressure-form machine which uses pressure above the mouthguard material to adapt the softened mouthguard material to the stone model. This machine offers a more consistent product with better adaptation but is more expensive. The pressure form machine is user friendly and many of the settings are automated. It is possible to laminate layers of material due to the heating process this method employees. In either case significant thinning occurs over the incisal edges and occlusal surfaces of teeth. In this area, EVA has an advantage over other materials since it can be laminated. Additional layers may be thermoformed and adhered to the first layer to increase overall thickness.

The lamination property of EVA allows for design modifications which include a middle layer of another material. The purpose of the middle layer is to improve shock absorption beyond the capabilities of EVA alone. Sponges, sorbothane, stainless steel wires, air inclusions, hard inserts, have all been used as intermediate layers (Knapik 2007). A spongy intermediate layer has proven to be the best improvement when it comes to shock absorption by reducing the transmitted force by 49% compared to EVA alone (deWett 1999). This was most likely due to absorption of the impact by the material and the buffer zone the material creates. This buffer zone may only be protective up to a certain impact force and may not be as protective with impact objects that are already soft These sorts of impact objects require distribution of force as opposed to energy absorption. In the same study by deWett et al (1999) the stainless steel wire performed 30% better than the EVA. The improvement observed by both a hard (stainless steel wire) and soft (sponge) layer points to different methods of reducing the transmitted impact. The sponge layer seems to have its effect through energy absorption and the stainless steel wire through force distribution. Although the stainless steel wire performed well, it poses obvious concerns. Stainless steel is very malleable and can permanently deform during ancillary deformation. In addition, a wire can protrude out of the mouthguard creating a potential for injury. An ideal intermediate material should overcome both of these issues such as nickel-titanium (NiTi) designed in a rectangular form.

All mouthguard shock absorption studies have been *in vitro* for obvious reasons. Most testing involves either a drop weight or a pendulum as a mode of impact. In the drop weight method, an impactor object of a known weight and hardness is selected. Traditionally, the impactor of choice has been a stainless steel object. Kinetic energy is calculated using the weight of the impactor and height at which it is released. The desired energy can be determined by varying the height or the impactor. In a pendulum testing apparatus, the impactor is attached to the end of the pendulum. In both methods, results are gathered using a force transducer or by recording rebound height.

Statement of Purpose

The purpose of this project was to improve shock absorption capabilities beyond the protection EVA alone can offer. This investigation involved a novel design where a layer of NiTi strip and/or foam is placed between layers of conventional EVA. The EVA layers were also varied in thickness. Each testing sample was compared to an EVA only control group of the same thickness. The rationale behind these design features was that the NiTi redistributed forces while the sponge layer absorbed forces.

Research Questions and Hypotheses

1. Will mouthguard configurations with the nickel-titanium intermediate layer offer greater shock absorption?

H_0: No, there is no difference in shock absorption between configurations with a NiTi intermediate layer when compared to EVA alone

$H_{A:}$ Yes, there is a difference in shock absorption between configurations with a NiTi intermediate layer when compared to EVA alone

2. Will configurations with a NiTi intermediate layer distribute forces better upon deflection in the simply supported beam testing method?

   H_0: No, there is no difference in shock absorption between configurations with a NiTi intermediate layer in the simply supported beam testing method when compared to results from the flat plate testing method

   $H_{A:}$ Yes, there is a difference in shock absorption between configurations with a NiTi intermediate layer in the simply supported beam testing method when compared to results from the flat plate testing method

3. Will porosity of the NiTi mesh play a role in shock absorption?

   H_0: No, porosity will not have an effect on shock absorption

   H_A: Yes, porosity will have an effect on shock absorption

4. Will a NiTi/sponge intermediate layer offer better shock absorption than either intermediate material by itself?

   H_0: No, the configurations with a NiTi/sponge intermediate layer will not perform better than either intermediate material by itself

   H_A: Yes, the configurations with a NiTi/sponge intermediate layer will perform better than either intermediate material by itself

5. If the novel designs provide better shock absorption, will thickness play a role?

H_0: No, thickness will not have an effect on the amount of protection offered by the novel designs

H_A: Yes, thickness will have an effect on the amount of protection offered by the novel designs

Chapter 2: Literature Review

Mouthguards were first introduced in the 1920s in the sport of boxing. Football players and coaches soon took notice and began experimenting with the use of mouthguards. By the 1960's, the use of mouthguards was mandated in many high school football and junior colleges. In 1973, the National Collegiate Athletic Association (NCAA) mandated athletes to wear mouthguards (Heintz 1975). The NCAA now requires a mouthguard in multiple sports including hockey, men's lacrosse, and women's field hockey. In 1998 New Zealand changed a rule requiring rugby players of all levels to wear a mouthguard. Although no law mandated by the government exists in the U.S. requiring athletes to wear mouthguards, the ADA recommends their use in 29 sports or activities (Knapik 2007).

Although the incidence of dental trauma in sports is minor compared to other injuries, the related recovery costs are high and disproportionate to the number of accidents. In 1992, the cost to replace a single lost tooth could cost $10-15,000, according to the National Youth Sports Foundation for the Prevention of Athletic injury Inc. On top of the cost, countless hours are spent in the dental chair and the injury can lead to other dental diseases such as periodontal problems. It is well documented that most dental injuries affect the maxilla, in particular the maxillary incisors (Newsome 2001). A study found that up to 80% of dental trauma is concentrated to the maxillary incisors (Stockwell 1988).

In general, there are three types of mouthguards. The most common is the mouth formed mouthguard, otherwise known as a boil and bite. This type is widely available and low cost. The athlete simply places the mouthguard in hot water and moulds it to his teeth by biting. The resulting product varies significantly and is generally not well adapted to the teeth resulting in a poor fit. This has a significantly negative effect on the mouthguard's shock absorption capability (Vieira 2008). In addition, this type of mouthguard can be very thin in critical areas such as the occlusal surface and incisal edges depending on the bite force, technique and variables such as mouth guard temperature at the time of moulding. Children with developing dentition can benefit from this design since it can be readapted to the changing dentition and cheap enough to simply replace once the fit worsens. One of the tradeoffs is the poor fit. Boil and bites have a generic flange extending to the vestibule which leads to poor adaptation, extension, and overall retention. Also, the molding process is sensitive and any deviation from the manufacturer's instructions may worsen the already poor fitting mouthguard. This short coming could be a distraction and even a hazard to an athlete during the event. The second type is a stock mouthguard which is the simplest of all the mouthguard options. This type is manufactured in a variety of sizes and is ready to use without further modifications. In other words, there is no moulding or adaptation process. The only retention comes from the wearers bite force and lip pressure. As a result, stock mouthguards have very poor fit and are the least protective of the three types (Patrick 2005). These mouthguards are commonly worn by those undergoing orthodontic treatment. Lastly, custom made mouthguards are those fabricated by a laboratory usually through a dental office. These offer the best fit and most protection (Patrick 2005). They are fabricated in a multi-step process, by first taking an impression of the patient's teeth, gums, and vestibule, and creating a stone model of the mouth. The dental laboratory then thermoforms a specially designed mouthguard material onto the stone model. The mouthguard material is typically ethylene vinyl acetate (EVA) and is trimmed and polished to its final form.

A mouthguard serves to reduce the likelihood of suffering from many types of orofacial injuries including mandibular fractures and concussions (Takeda 2005). Mouthguards also reduce laceration and bruising of the lips and cheeks by separating soft tissue from hard tissue. Lastly, absorbing and redistributing potentially damaging blows as well as protecting teeth by discluding the maxillary and mandibular teeth from contacting each other during strenuous physical activity.

There are many physical properties that are important in mouthguard material. Ideally, the material should have high shock absorption, high tensile strength, low water absorption, high tear strength, biocompatible, suitable for the oral environment, and a balance between hardness and stiffness. Many materials were investigated over the years.. Among these materials were Ethylene Vinyl Acetate (EVA), PolyUrethane (PU), rubber latex, thermoplastic material, PolyVinyl Acetate (PVC), silicon, and different resins (Craig&Godwin 1967; Going 1974; Loehman 1975). They found that although EVA was not the most shock absorbent material in all three studies, it did perform exceptionally well. Another study found silicone rubbers with variation in glass fibers and silicone oils were also comparable to EVA in shock absorption and biocompatibility but not necessarily better (Auroy ’96). With these findings, EVA has become the most commonly used material for its superior shock absorption, ease in fabrication, and relative safety.

The research done in this study dealt with shock absorption. This property is a function of protection. All mouthguard shock absorption studies have been *in vitro* for obvious reasons. Most testing involves either a drop weight or a pendulum as a mode of impact. In the drop weight method, an impactor object of a known weight and hardness is selected. Traditionally, the impactor of choice has been a stainless steel object. Kinetic energy is calculated using the weight of the impactor and height at which it is released. The desired energy can be determined by varying the height or the impactor. In a pendulum testing apparatus, the impactor is attached to the end of the pendulum. In both methods, results are gathered using a force transducer or a record of rebound height. Most studies use around 1-4J of potential energy.

One of EVA's main components is polyvinyl acetate (PVA). This component increases the shock absorption and decreases water absorption in mouthguards but at the same time decreases hardness and tear strength. It became important to determine the optimal ratio of PVA that offers the most shock absorption without compromising other properties. Researchers attempted to answer that very question by testing different physical properties of EVA at varying PVA ratios. 9 samples were tested for energy absorption, compressibility, and tear strength. They found that 18% PVA provided the most shock absorption while still offering the desired characteristics of low water sorption, high tear strength, good elasticity and compression behavior (Bishop 1985). Today, the exact ratio of PVA and other ingredients are not freely disclosed by companies and are in some cases proprietary.

Another aspect of mouthguard research relates to the appropriate thickness. Park et al (1994) decided to investigate this matter due to concerns of material thinning during the fabrication of boil and bite mouthguards and custom made mouthguards. The researchers wanted to know if sufficient protection was being offered by mouthguards that were thinned in certain areas of the appliance. Park et al used two steel balls of different diameter as the impactor and a drop tower testing method. Samples were made in 4 varying thicknesses: 1, 1.5, 2, and 4mm EVA. The intuitive thought that protection is decreased with decreased thickness was confirmed by this study (Park 1994). Later, Westerman et al (2002) discovered this was true only to a point. This group of researchers tested 5 different thicknesses of EVA: 1, 2, 3, 4, 5, and 6mm. A pendulum testing method was used to strike each sample with a force strong enough to cause damage to orofacial structures. There was great improvement in protection as the thickness increased from 2mm to 4mm. After 4mm, the improvement in shock absorption tapers off and little benefit is observed with the thicker thicknesses. They concluded that a 4mm thickness provided a balance between protection and comfort, and anything thicker than 4mm only offered a minute amount of increased protection.

Many modifications have been attempted in an effort to produce a mouthguard more shock absorbent than EVA alone. Most modifications take advantage of the lamination property of EVA. Foams, sorbothane, stainless steel wires, air inclusions, hard inserts, have all been used as intermediate layers (Knapik 2007). De Wet et al experimented with a stainless steel wire and foam as the intermediate layer. All testing samples were roughly 5mm thick. They found that the mouthguard with a spongy intermediate layer performed the best. This design was able to reduce the transmitted force by 49% compared to EVA alone (deWett 1999). This was most likely due to absorption of the impact by the material and the buffer zone the material creates. This buffer zone may only be protective up to a certain impact force and may not be as protective with impact objects that are already soft and require an intermediate layer that distributes the force as opposed to absorbs the energy. In the same study by, the stainless steel wire performed 30% better than the EVA control (1999). The improvement observed by both a hard and soft layer points to different methods of reducing the transmitted impact. The foam layer seems to have its effect through energy absorption and the stainless steel wire through force distribution.

Many factors play a role when it comes to wear compliance such as: comfort, wearability, stability, retention, speech, ability to breadth, and appearance. The mouthguard must be comfortable and not feel awkward or distracting in the athlete's mouth. Factors that play a big role in this area are design and thickness of the mouthguard. In addition, stability and retention are closely related to the adaptation method. A custom-made mouthguard offers a superior fit than the other options due to its fabrication method (Deyounge 1994). Also, many wearers must be able to talk while participating in their respective sports. Therefore, the mouthguard should not impede speech. Many athletes cite this as the reason they forgo the use of a mouthguard (Westerman 2002). Breathing is a key determinant to whether an athlete uses a mouthguard. Anecdotal accounts from athletes about breathing difficulties due to a mouthguard have been around for many years. Francis et al did in fact find this to be true along with increased resistance to air flow (1991). A possibility is the discomfort that was felt by the subjects in the study could be tied to bulky mouthguard designs. In a study done by Vieira et al, they found that rugby players thought custom-made mouthguards offered a superior breathing and speaking capability than a boil and bite mouthguard (2008). The ideal mouthguard would offer a balance between the aforementioned factors and protection from damaging blows experienced while participating in some form of activity.

Since many sports have both high and low impact forces such as basketball, materials or mouthguard designs that confer force distribution and absorption have been studied. A stiffer material is better equipped to distribute high impact forces, similar to the role the stainless steel wire played in the study previously mentioned. Nickel-titanium metal may be stiff enough to serve this purpose. In addition, it is well known for its superelasticity and shape memory which are ideal properties to retain its form during placement and removal along with any ancillary deformations. Nickel-Titanium has a good track record in the medical field as a biocompatible material and is consistently used in both the medical and dental field. As previously stated, an intermediate foam layer has proven to be very effective at energy absorption (de Wet 1999). The use of both NiTi and foam simultaneously as an intermediate layer can potentially add more versatility to the types of impacts sustained. This design may solve the hard versus soft impact dilemma and preclude many sport-specific mouthguards.

Chapter 3: Methods and Materials

Our novel design incorporates a NiTi facial intermediate layer from canine to canine. The NiTi strip is intended to distribute forces over a larger surface area. Previous designs incorporated a stainless steel wire which provided the same role but posed safety concerns (deWett 1999). A rectangular strip design addresses the safety issues posed by a wire that could potentially cause soft tissue damage. Furthermore, porosities were added to allow for variation in stiffness and to allow the two EVA layers to laminate together within the strip providing better mechanical retention. As previously stated, mouthguards with an intermediate foam layer have been one of the most shock absorptive designs (de Wet 1999). Additional to the NiTi, a sponge layer posterior to the NiTi strip can provide further shock absorption properties and even allow more deformation of the NT strip. This combined intermediate layer is well suited to deal with a range of impact forces making it more versatile in its use.

A total of 260 mouthguard testing samples were fabricated for this study, consisting of 210 experimental samples and 50 control samples. A total of 7 experimental configurations were investigated, each at 3 different thickness groups. The different configurations consisted of EVA outer layers and varied in intermediate layer composition. They were fabricated into flat rectangles with dimensions approximating the anterior region of the mouth from incisal edge to vestibule. Flat samples meant to represent mouthguards are common in the literature and were chosen in this study to control for a multitude of variables (Knapik 2007).

Two test methods were employed using a drop tower. The first method involved a testing sample being placed over a flat aluminum plate. A load cell was placed under the plate and the peak force transmitted through the sample was recorded. In the second method, a simply supported aluminum beam was used and is discussed more thoroughly later.

Ethylene Vynil Acetate

Conventional EVA was purchased from the manufacturer for the fabrication of mouthguards (Great Lakes Orthodontics, Tonowanda, NY). EVA was chosen over other commercially available materials because it is the most commonly used material to fabricate mouthguards and it’s the standard testing material in previous studies. To achieve varying thicknesses among the groups, EVA layers of different thicknesses were laminated. EVA layers with the initial thicknesses of 1mm, 2mm and 3mm were used (Figure 1). Each layer came in a 125mm diameter circular plate designed to fit the fabrication machine.

Figure 1. EVA at different thicknesses

Nickel-Titanium

One Nickel Titanium sheet of a 103x455x.33mm was purchased and processed for the fabrication of the intermediate layer strips (Memry GmbH, Weil am Rhein, Germany). The NiTi sheet was of the superelastic type and annealed oxide free. The sheet was sent to an outside company to be laser-cut into 27 strips, each measuring 48mm in length and 9mm in width (Directed Light Inc, San Jose, CA). These dimensions were chosen to approximate the maxillary canine to canine region. The strips were designed to be cut into 3 configurations varying in porosity (Figure 2). In order to achieve the desired porosity, 1.5mm holes were laser cut and spaced evenly. A simple way of classifying these three groups is as a percentage of porosity to overall area of the NiTi strip. For example, 0% porosity means no holes were cut into the NiTi strip. Our three designs consisted of 0%, 31%, and 50% porosity.

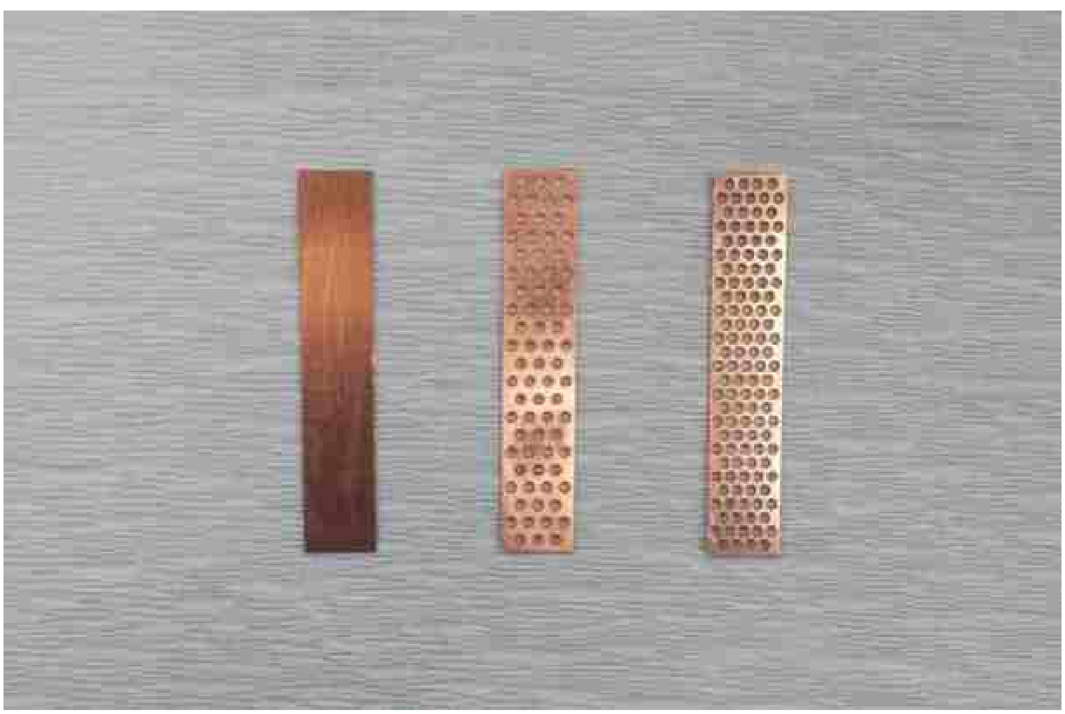


Figure 2. three different porosities of NiTi strips

Foam

A PVC foam tape was purchased from McMaster-Carr. Foam in the tape form proved to be the best option in order to achieve a predictable thickness. The foam was .79mm thick and had acrylic adhesive on both sides (Figure 3). The final length and width was made to the same dimensions of the NiTi strip, 48mmx9mm.

Figure 3. Foam tape

Fabrication

A Ministar S pressure forming machine illustrated in figure 4 was used to fabricate mouthguard samples in this study (Great Lakes Orthodontics, Tonewanda, NY). A pressure forming machine was chosen over a vacuum form due to its consistency and ease of use. The process began with the outlining of 3 mouthguard samples on the EVA inner layer. Intermediate layers were then placed on this layer of EVA in the outlined position. The outer EVA plate was heated to the manufacturer's specification and laminated to the inner layer. The machine automatically determined the amount of time and pressure needed to complete the process. In order to avoid air bubbles in our samples two 1mm holes were made on the inner layer before lamination. These holes were made at each end of the sample and were far from the area of impact. The final dimensions of the samples were made using a box cutter and a metal ruler as a guide and cutting edge (Figure 5). Using a fine cutting instrument like a box cutter allowed for precise dimensions.

Figure 4. Ministar S pressure forming machine

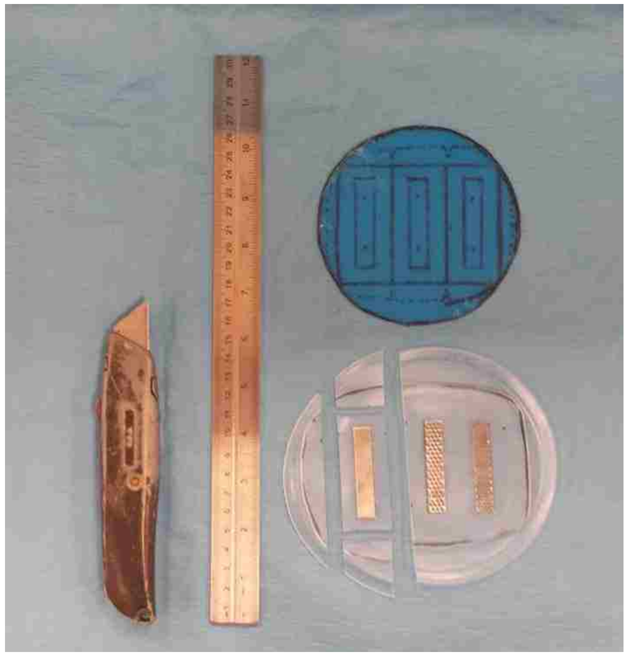


Figure 5. Fabrication of testing samples

The fabrication of the experimental samples with a NiTi strip was limited by the quantity of strips available. Due to the high cost, only 9 strips per porosity design were fabricated and thus had to be reused. Care was taken to remove the strips without any damage. Any residual adhesive left on the NiTi strip from the foam was removed using acetone.

Testing

An Instron™ Dynatup drop tower was used in this experiment and is shown in figure 6 (Norwood, MA). The testing samples were placed on an aluminum plate and secured with a double sided tape. A 5000lbf load cell was attached to an aluminum plate that was bolted to the base of the drop tower. This force sensor was made by PCB Piezotronics model 200M70 ICP® (Depew, NY). A 2” diameter aluminum cylinder was used as the impactor. The cylinder was attached to a larger unit that was held by two aluminum plates bringing the total weight of the impactor to 2.745kg (Figure 7). The impactor unit was then dropped from a two inch height onto the center of the testing coupon. The two inch height was set at the beginning of the experimental set up using a rectangular metal block (Figure 7). The drop tower was configured to automatically return to the same height after every round of testing. The total potential energy as determined from the mass, height, and gravity was 1.368 Joules.

Figure 6. Instron^{TM} Dynatup drop tower

Figure 7. Impactor components and method used to set height

Two testing methods were used in this investigation. The first was a flat plate testing which allowed for a standard reading of shock absorption (Figure 8). Upon releasing the impactor, gravity was the driving force of impaction and the load cell recorded the transmitted force. This method is a common method of testing shock absorbency but has some shortcomings. The flat plate testing only allows for compression as a form of shock absorbency. The maxillary complex itself experiences some deflection at impact. The traditional flat plate testing design does not allow deflection and negates a form of energy dissipation. Our second configuration, the simply supported beam testing, was designed to allow for minor deflection at impact (Figure 9). No attempt was made at replicating the exact deflection exhibited by a human's anterior maxillary complex as this would be extremely challenging and varies greatly. This test recorded strain as well as peak force. The aluminum plate from the flat plate test was modified to accept two 0.25” diameter steel dowel pins 3.5” apart. A 4”x2”x.25” aluminum plate was then placed on top of the dowel pins to create a simply supported beam. The supported plate allowed for some give which was recorded through a strain gauge attached under the beam (Vishay, model CEA-06-240UZ-120). Force-time data and strain-time data were collected in this configuration.

Figure 8. Flat plate testing method

Figure 9. Simply supported beam testing method

The peak force and strain data was recorded on a Yokogawa DL750 ScopeCorder oscilloscope. The reading first passed through a signal conditioner before being recorded on the oscilloscope. Data was collected at a rate of 1 million samples per second. The oscilloscope was configured to record 20% of the data prior to impact, which was about 2 milliseconds.

Testing Groups

Seven configurations were fabricated at 3 different thicknesses (Table 1). The first 3 configurations consisted of only a NiTi strip laminated between two EVA layers. The NiTi strips in these three configurations varied in porosity: 0%, 31%, 50%. The fourth configuration consisted of a foam intermediate layer. The last three configurations consisted of a NiTi strip anterior to a foam layer varying in porosity.

Thicknesses were varied by using different inner and outer EVA thickness plates. One thickness group was fabricated with a 1mm outer EVA layer, an intermediate layer, and a 1mm inner EVA layer. This thickness group was designated the 1-1 group. The second thickness group consisted of a 1mm outer EVA layer, an intermediate group, and a 2mm inner group. Configurations with these layers fell under the 1-2 group. Finally, the 2-2 group consisted of configurations with a 2mm outer EVA layer, an intermediate layer, and a 2mm outer EVA layer.

The control groups were laminated EVA sheets of 1mm/1mm, 1mm/2mm, 2mm/2mm, 2mm/3mm, 3mm/3mm, with no intermediate layer. The 2-3 and 3-3 controls are not shown in figure 9.

The configurations were labeled based on their composition. The labeling consisted of a number representing the outer EVA thickness, an abbreviation for the intermediate layer, a number representing the inner EVA thickness, and a percentage representing the porosity of the NiTi layer when appropriate. For example, a 1NF2 50% represents the configuration with a 1mm outer EVA layer, a NiTi and Foam intermediate layer, a 2mm inner EVA layer, and the NiTi strip has a 50% porosity.

In all, twenty-one experimental testing groups falling into 3 thickness groups were fabricated. In addition, five control groups were fabricated, one per thickness group and two of thicker dimensions.

Table 1.

Testing Matrix

	1-1 Group	1-2 Group	2-2 Group
Control	1-1 Con	1-2 Con	2-2 Con
EVA/NT/EVA	1N1 0%	1N2 0%	2N2 0%
	1N1 31%	1N2 31%	2N2 31%
	1N1 50%	1N2 50%	2N2 50%
EVA/Foam/EVA	1F1	1F2	2F2
EVA/NT-Foam/EVA	1NF1 0%	1NF2 0%	2NF2 0%
	1NF1 31%	1NF2 31%	2NF2 31%
	1NF1 50%	1NF2 50%	2NF2 50%

Chapter 4: Results

Flat Plate Testing

Three test groups were produced by thermoforming layers of EVA of 1 and 2 mm thicknesses together. Results for this test were broken down into 3 groups: 1mm EVA-1mm EVA (1-1 group), 1mm inner EVA-2mm outer EVA (1-2 group), and 2mm EVA-2mm EVA (2-2 group). The results for each group are given in chart form in Figure 10-12. The same information is also illustrated in figure 13 in as a graph plotting thickness against peak force transmitted through the sample. Therefore, the higher the transmitted force the less shock absorption the sample offers. In addition to the three control thicknesses that pair with each group, two more EVA-only controls of a 5mm and 6mm thickness were tested and can be seen in figure 13.

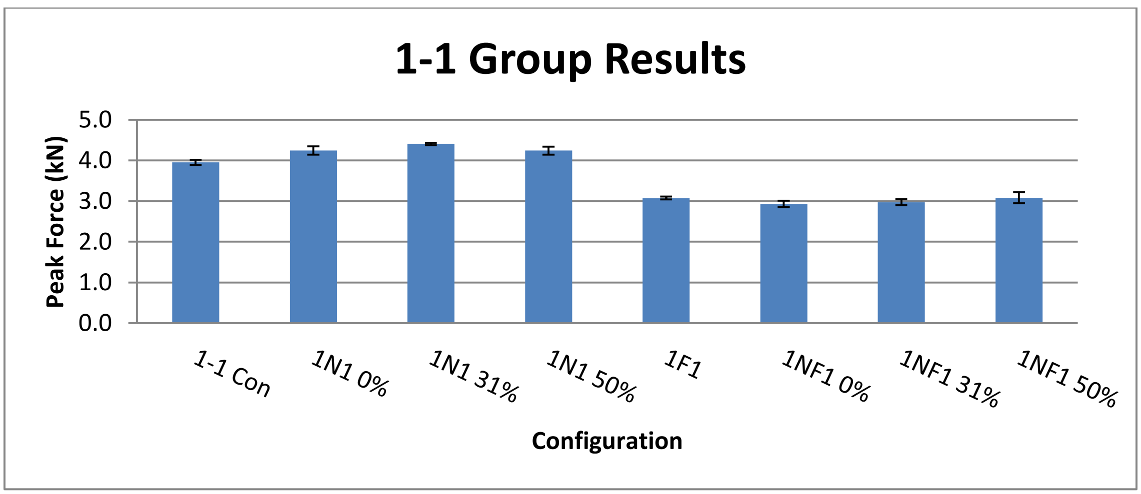


Figure 10. Transmitted peak force for 1-1 group

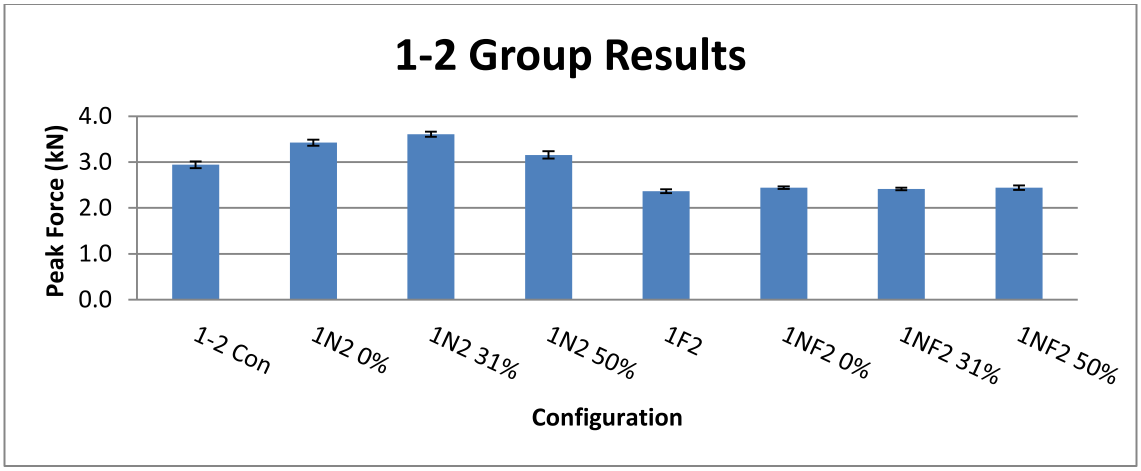


Figure 11. Transmitted peak force for 1-2 group

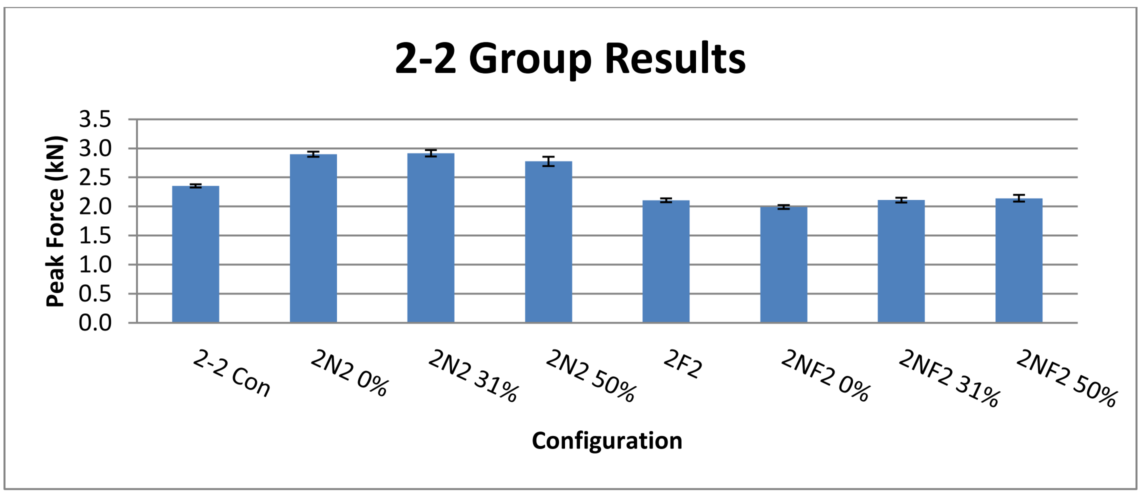


Figure 12. Transmitted peak force for 2-2 group

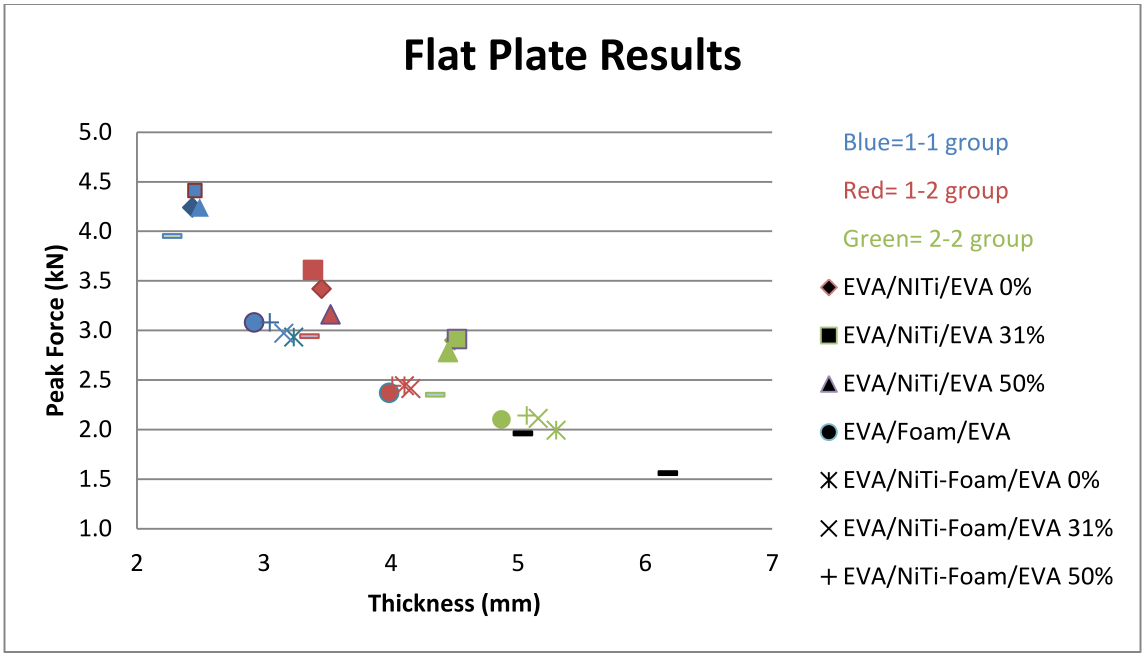


Figure 13. Results from flat plate testing

Figures 10-13 indicate that there is not a linear relationship between thickness and transmitted peak force. That is, there are large decreases in transmitted peak force as thicknesses increase in the thinner samples but the decrease in transmitted force begins to taper in the thicker samples.

An analysis of variance (ANOVA) was done to determine if there was a difference between the 3 types of porosities (Appendix A). A summary of the results are given in table 2. In all cases except the 1N2 group had no statistical significance. The difference in stiffness by varying the porosity of the NiTi strip did not seem to have much effect on the transmitted force. The three porosities behaved the same except for in one group. In any case, the 1N2 configurations performed significantly worse than the EVA control.

Table 2

Summary of ANOVA Comparison of Porosities in Flat Plate Test

Summary of ANOVA Comparison of Porosities			
config	F	P-value	F-critical
1N1-0%, 31%, 50%	1.37	0.27	3.35
1N2-0%, 31%, 50%	8.41	0.001*	3.35
2N2-0%, 31%, 50%	1.53	0.24	3.35
1NF1-0%, 31%, 50%	0.59	0.56	3.35
1NF2-0%, 31%, 50%	0.19	0.83	3.35
2NF2-0%, 31%, 50%	3.08	0.06	3.35

Although the same EVA layer thicknesses were used within each of the three groups, the overall thicknesses varied between the different configurations due to the addition of an intermediate layer. In order to normalize for thickness, a curve was fitted to the transmitted peak force of the EVA-only (Figure 14). The two additional control groups of the 5mm and 6mm thickness were used to give a more complete set of data and a more accurate fitted curve.

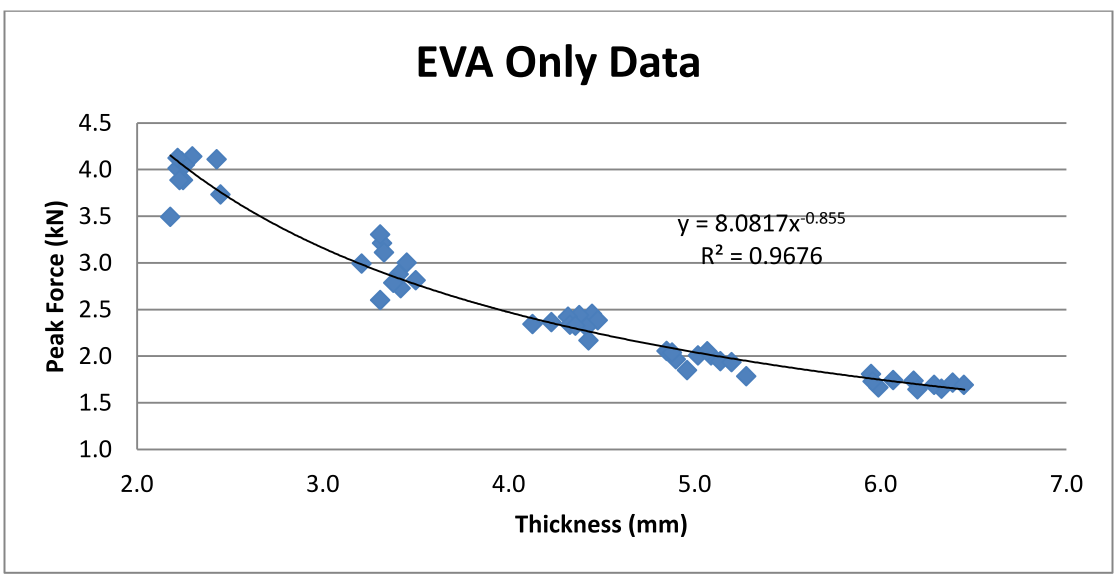


Figure 14. Best Curve Fit of EVA-only Controls

Using the formula yielded by the fitted curve, configurations of the same thickness group was compared to a calculated EVA-only sample of the same thickness. Figures 15-17 illustrate this information.

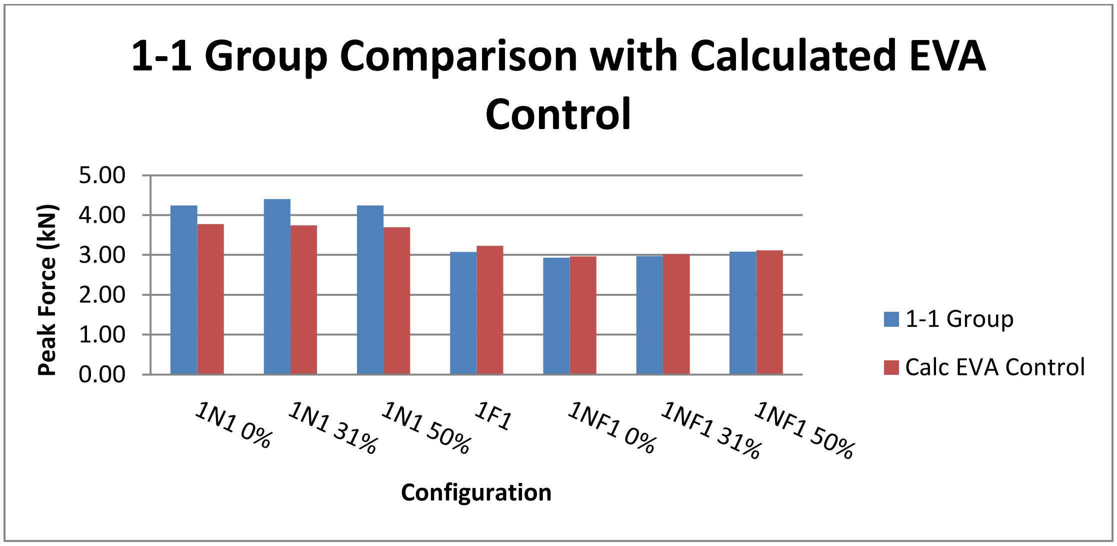


Figure 15. Comparison of 1-1 group with the calculated EVA control

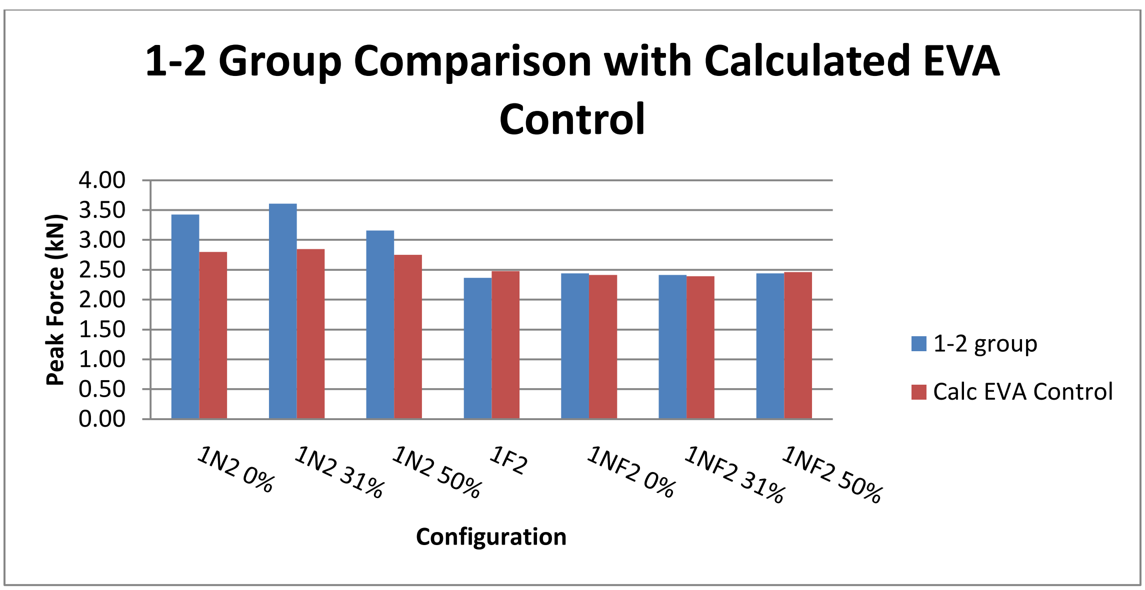


Figure 16. Comparison of 1-2 group with the calculated EVA control

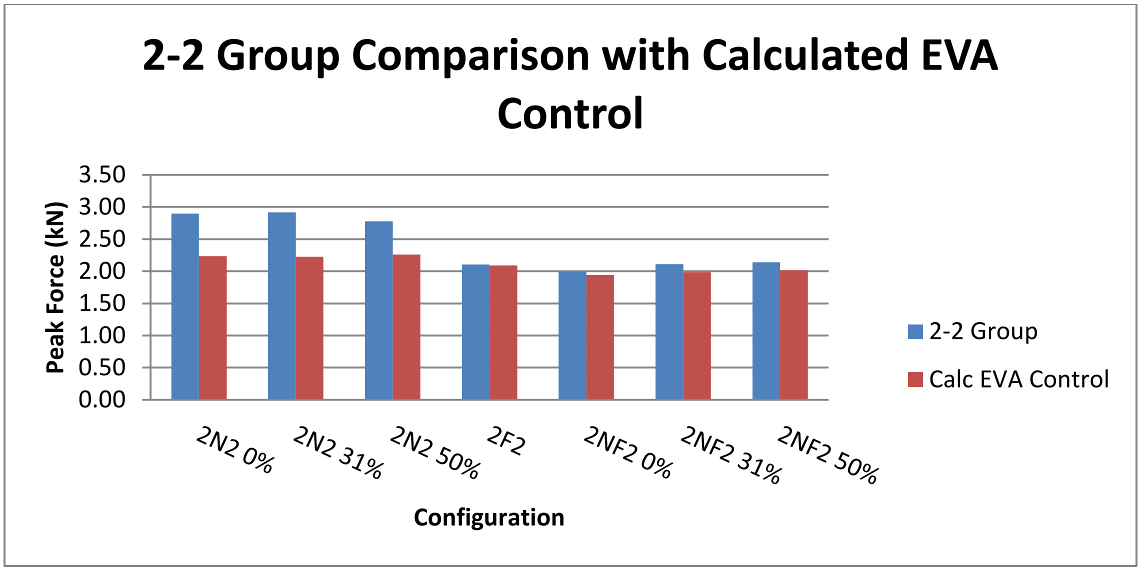


Figure 17. Comparison of 2-2 group with the calculated EVA control

Using the curve fit data, a confidence interval of ±95% was calculated. Figure 19 shows the different configuration groups based on intermediate layer and plotted based on thickness. The confidence intervals are displayed by the dotted curves. Sample means found outside of the curves were statistical different when compared to the control. In order to simplify figure 18, samples containing NiTi were not separated based on porosity as no differences were found between the porosities except for one. The data is also presented in tables 3-5.

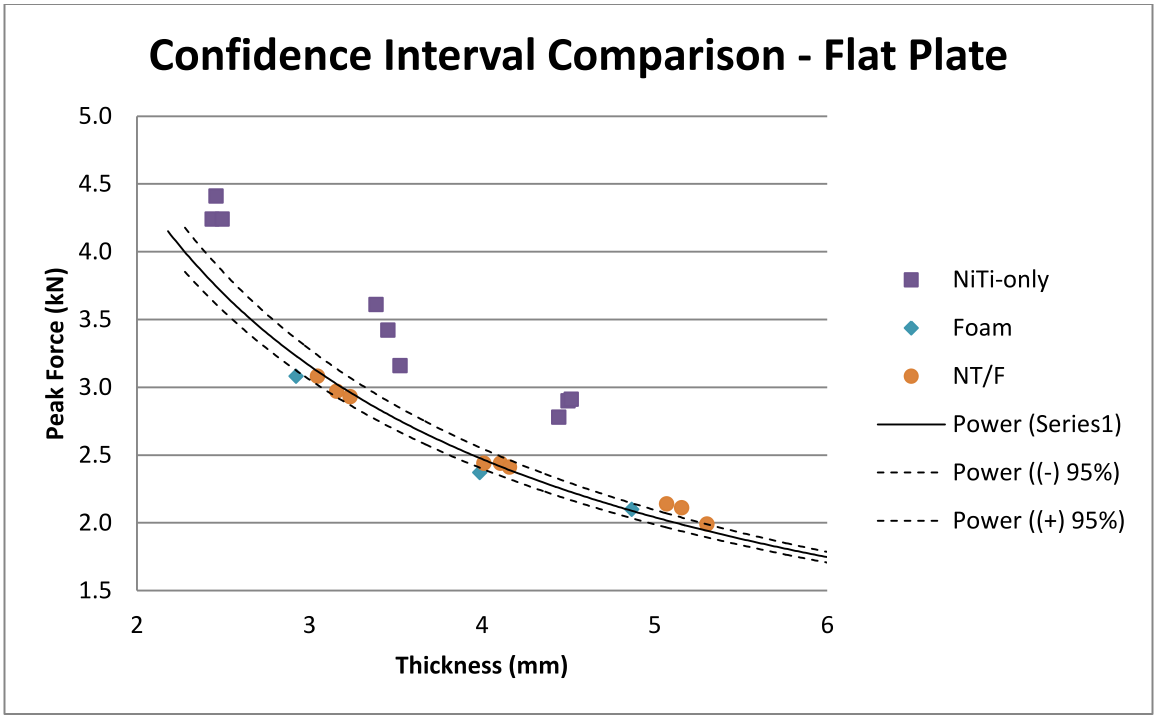


Figure 18. Confidence Interval comparison in the flat plate test

Table 3.

95% CI for 1-1 Group

Flat Plate-Confidence Interval Comparison: 1-1 Group				
config 1-1	thickness	peak (kN)	-95%	95%
1N1 0%	2.44	4.24*	3.64	3.94
1N1 31%	2.46	4.41*	3.61	3.91
1N1 50%	2.50	4.24*	3.57	3.86
1F1	2.92	3.08*	3.12	3.36
1NF1 0%	3.24	2.93	2.87	3.07
1NF1 31%	3.16	2.97	2.93	3.13
1NF1 50%	3.05	3.08	3.02	3.24

Table 4.

95% CI for 1-2 Group

Flat Plate-Confidence Interval Comparison: 1-2 Group				
Config 1-2	**thickness**	**peak (kN)**	**-95%**	**95%**
1N2 0%	3.46	3.42*	2.71	2.90
1N2 31%	3.39	3.61*	2.76	2.95
1N2 50%	3.53	3.16*	2.67	2.85
1F2	3.99	2.37*	2.41	2.56
1NF2 0%	4.11	2.44	2.35	2.49
1NF2 31%	4.16	2.41	2.32	2.46
1NF2 50%	4.01	2.44	2.39	2.54

Table 5.

95% CI for 2-2 Group

Flat Plate-Confidence Interval Comparison: 2-2 Group				
config 2-2	**thickness**	**peak (kN)**	**-95%**	**95%**
2N2 0%	4.50	2.9*	2.17	2.30
2N2 31%	4.52	2.91*	2.17	2.29
2N2 50%	4.45	2.78*	2.19	2.32
2F2	4.87	2.10	2.03	2.14
2NF2 0%	5.30	1.99	1.89	1.99
2NF2 31%	5.16	2.11*	1.94	2.04
2NF2 50%	5.07	2.14*	1.97	2.07

The NiTi-only intermediate layer configuration performed statistically worse than the calculated EVA-only control of the same thickness in all three thickness groups. Tables 3-5 show the NiTi-only configurations transmitted 0.3-0.6kN more than the upper limit of the 95% confidence interval. As mentioned above, the change in porosity did not influence the performance of the samples except for the 1N2 group. Varying the Stiffness of the NiTi strip seemed to play no role in shock absorption. The foam groups performed the best and had a statistically significant improvement in shock absorption. The 1-1 and 1-2 groups transmitted a peak force of 3.08, 95% CI[3.12, 3.36], and 2.37, 95% CI[2.41, 2.56], respectively. The 2-2 foam configuration seemed to behave more like the EVA control transmitting 2.10 kN of peak force and did not have a statistically significant gain in shock absorption (95% CI[2.03, 2.14]). As for the configurations with both a NiTi and foam intermediate layer, they performed the same as the calculated EVA-only control in the 1-1 and 1-2 thickness groups. The 1NF1 and 1NF2 configurations all tested within the ±95% CI range (Table 3-4). In the 2-2 group, all three NF configurations transmitted a peak force at or above the 95% confidence interval (Table 5). Therefore, the Niti/foam configurations in the 2-2 group performed statistically worse than the calculated control.

Another analysis that was done in order to confirm our results was an ANOVA. This was done by comparing each configuration to a control sample with the closest thickness. Therefore, the 1-1 configurations were individually compared to the 1-2 control sample. The same was done for the 1-2 and the 2-2 configurations. The full results of the ANOVA analysis can be found in Appendix B. Tables 6-8 show the summary of the results.

Table 6.

Summary of 1-1 Group ANOVA Comparison to 1-2 Control

Summary of 1-1 Group ANOVA Comparison to 1-2 Control			
config	**F**	**P-value**	**F-critical**
1N1 0%	109.68	4.37E-9*	4.41
1N1 31%	377.83	1.57E-13*	4.41
1N1 50%	119.07	2.29E-9*	4.41
1F1	2.79	0.11	4.41
1NF1 0%	0.01	0.93	4.41
1NF1 31%	0.08	0.78	4.41
1NF1 50%	0.83	0.37	4.41

Table 7.

Summary of 1-2 Group ANOVA Comparison to 2-2 Control

Summary of 1-2 Group ANOVA Comparison to 2-2 Control			
config	**F**	**P-value**	**F-critical**
1N2 0%	216.63	1.77E-11*	4.41
1N2 31%	384.59	1.35E-13*	4.41
1N2 50%	57.32	5.32E-7*	4.41
1F2	0.05	0.82	4.41
1NF2 0%	5.02	0.037904*	4.41
1NF2 31%	2.28	0.15	4.41
1NF2 50%	2.63	0.12	4.41

Table 8

Summary of 2-2 Group ANOVA Comparison to 2-3 Control

Summary of 2-2 Group ANOVA Comparison to 2-3 Control			
config	**F**	**P-value**	**F-critical**
2N2 0%	322.23	6.17E-13*	4.41
2N2 31%	235.03	8.94E-12*	4.41
2N2 50%	92.21	1.66E-8*	4.41
2F2	10.40	0.004703*	4.41
2NF2 0%	0.47	0.50	4.41
2NF2 31%	8.16	0.010494*	4.41
2NF2 50%	8.09	0.010779*	4.41

The ANOVA analysis shows that in all three thickness groups the Niti-only configurations tested significantly different from the control ($P<.05$). No significant difference was found in the foam-only configurations except in the 2-2 group. This was the opposite finding from the confidence interval analysis. For the NiTi/foam configurations, only three had statistically significant results. The 1NF2 0%, 2NF2 31%, and 2NF2 50% had a P value below .05. The 2NF2 configuration results were above the 95% confidence interval in the previous analysis. This was similar to what was observed with the ANOVA analysis except for the 2NF2 configuration.

One must be careful interpreting the data yielded from the ANOVA analysis. It is not possible to normalize for thickness using ANOVA. A percent difference in thickness from the control sample was calculated for each configuration. The configurations with the thicker intermediate layer like the NiTi/Foam group did not differ much from the control (Appendix C). On the other hand, the NiTi-only configurations showed the largest difference from the control, especially in the thinner samples.

Simply Supported Beam Method

In this method, deflection was introduced as a form of energy absorption. A sample was placed on a simply supported beam and the deflection was recorded as strain energy, along with transmitted peak force. Figures 19-21 show the peak forces and strains for each thickness group and the associated standard errors.

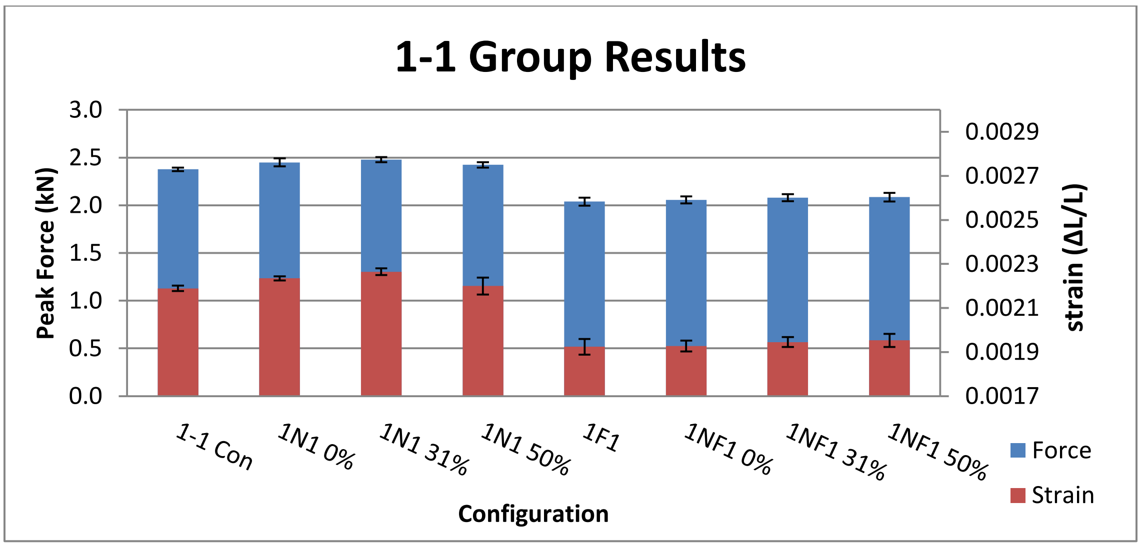


Figure 19. Peak force and strain energy results for the 1-1 group

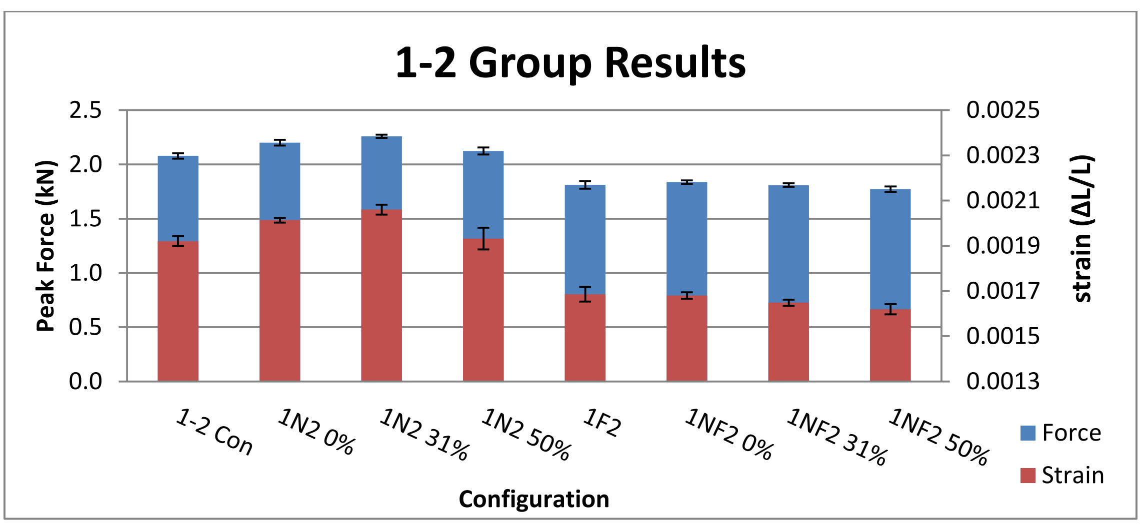


Figure 20. Peak force and strain energy results for the 1-2 group

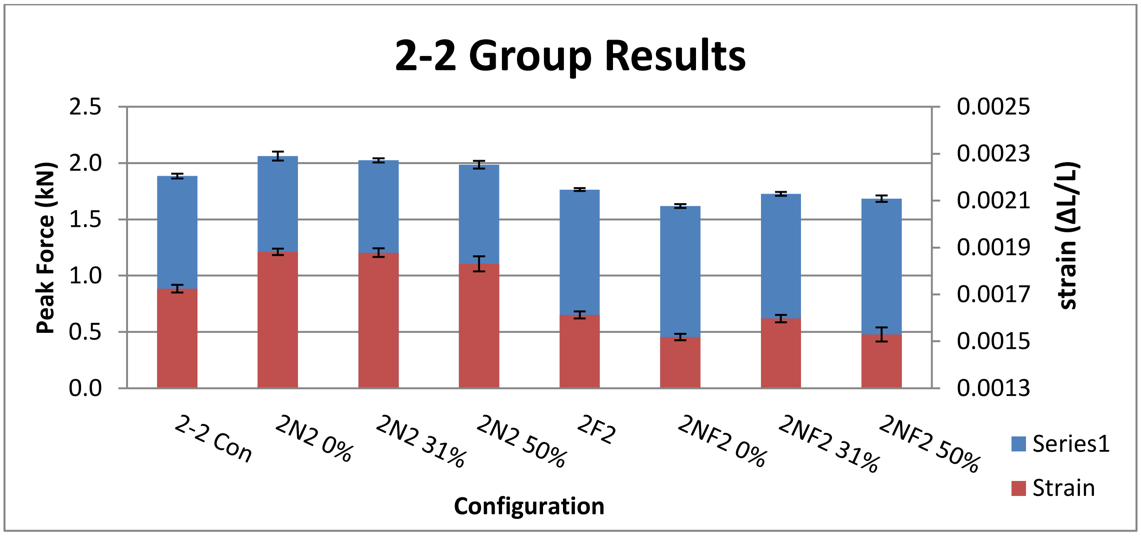


Figure 21. Peak force and strain energy results for the 2-2 group

Recording strain energy allows us to form a more complete picture. It is possible to calculate the energy that is absorbed by the sample by performing a simple energy balance. A few assumptions must be made in order to do this. First, one must assume a uniform distribution of force with the same magnitude as the actual distribution. Second, the system becomes static at the point peak force and strain reaches its highest reading. This means the energy is either absorbed by the sample or transferred into strain energy. Lastly, any other source of energy dissipation, such as heat, is ignored. Accepting these assumptions, the following formula is true:

$$E_A = E_k - U$$

Where E_A is energy absorbed by the sample, E_k is kinetic energy with which the sample is struck with, and U is strain energy. E_k was calculated for each sample in order to account for the change in impactor height due to varying thickness in samples. The energy absorbed was then divided by the thickness of the tested sample and expressed as a percentage:

$$\frac{\%Abs}{mm} = \frac{E_A/E_k x100}{thickness}$$

As with the flat plate testing, the results cannot be compared to the EVA-only control of the same thickness group because the thicknesses within the group vary significantly. Therefore, results from figures 19-21 can be misleading. To normalize for thickness the same method was employed as with the previous test. The EVA-only control samples were plotted and a curve fit was calculated as with the flat plate testing method (Appendix D). The curve allowed for normalization of thickness and each configuration was compared to a calculated EVA-only control of the equivalent thickness in figure 22-24.

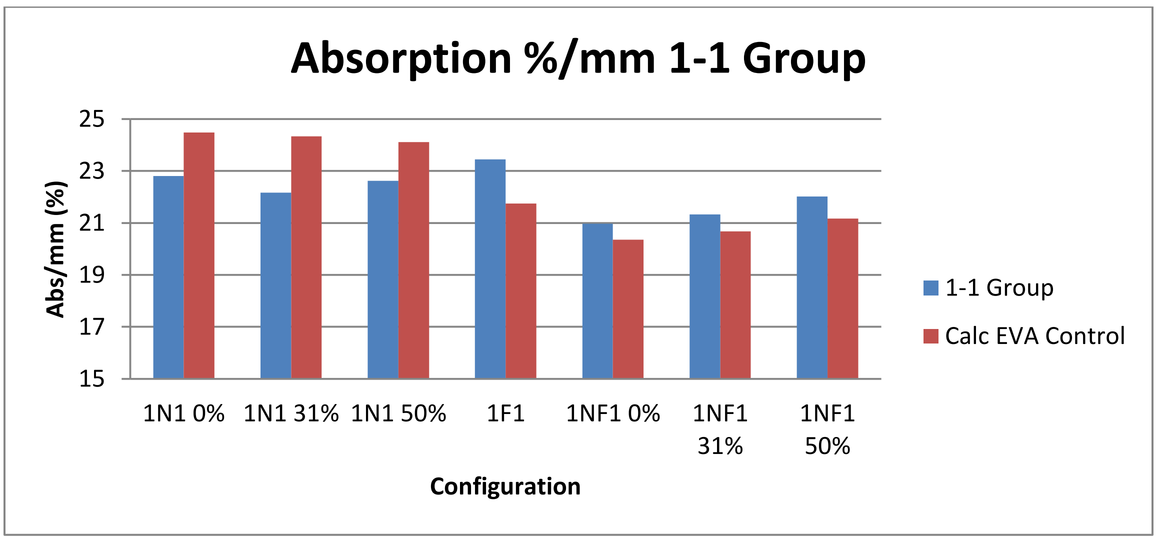


Figure 22. 1-1 Group: percent of energy absorbed per mm Compared to Calc. Control

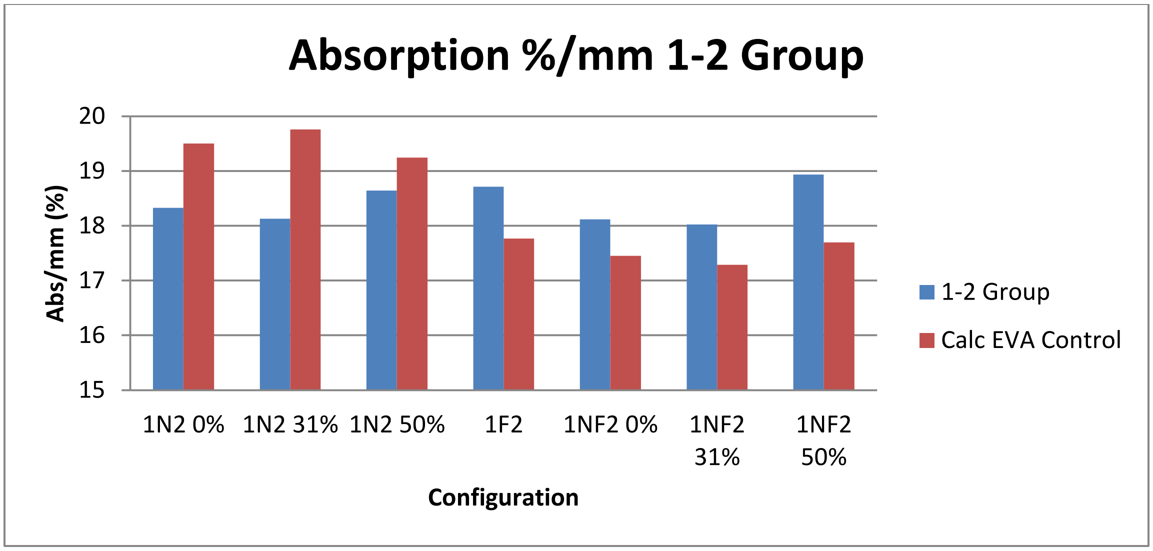


Figure 23. 1-2 Group: percent of energy absorbed per mm Compared to Calc. Control

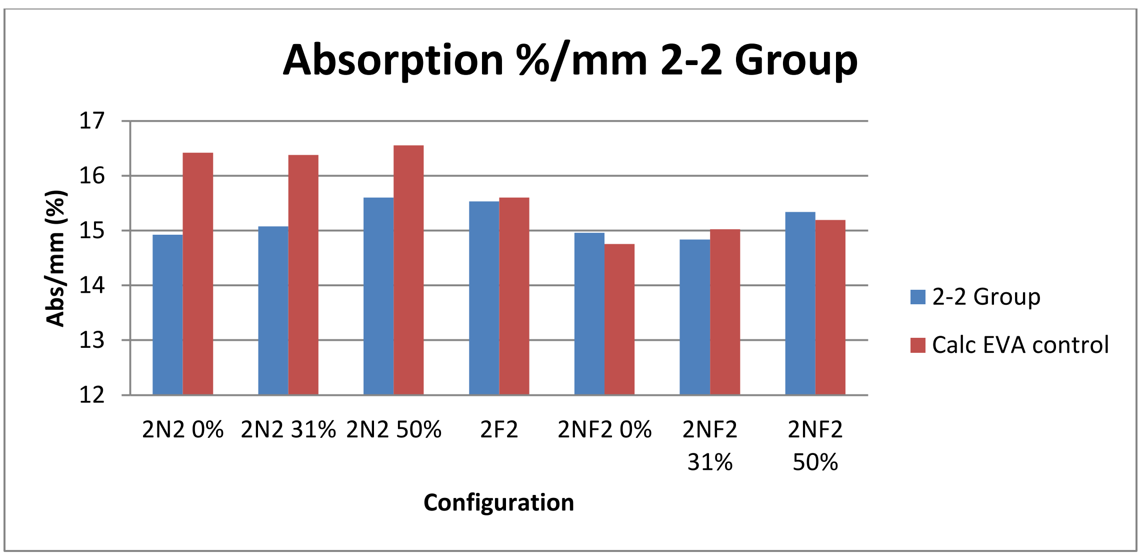


Figure 24. 2-2 Group: percent of energy absorbed per mm Compared to Calc. Control

Another form of illustrating the same data is through the percent difference between the novel configurations and the calculated EVA controls (fig. 25-27).

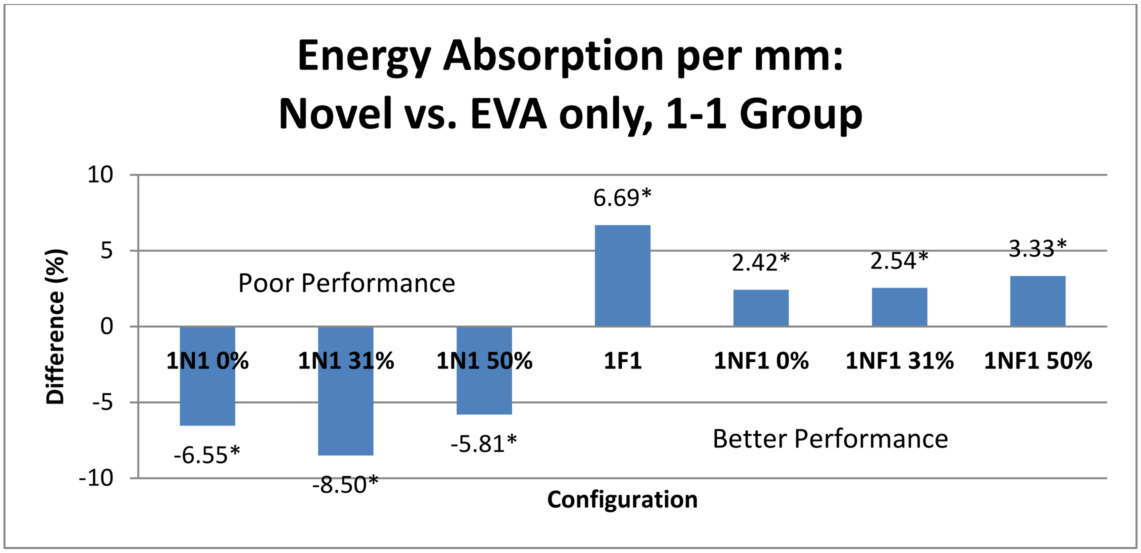


Figure 25. 1-1 Group: percent difference compared to calculated control

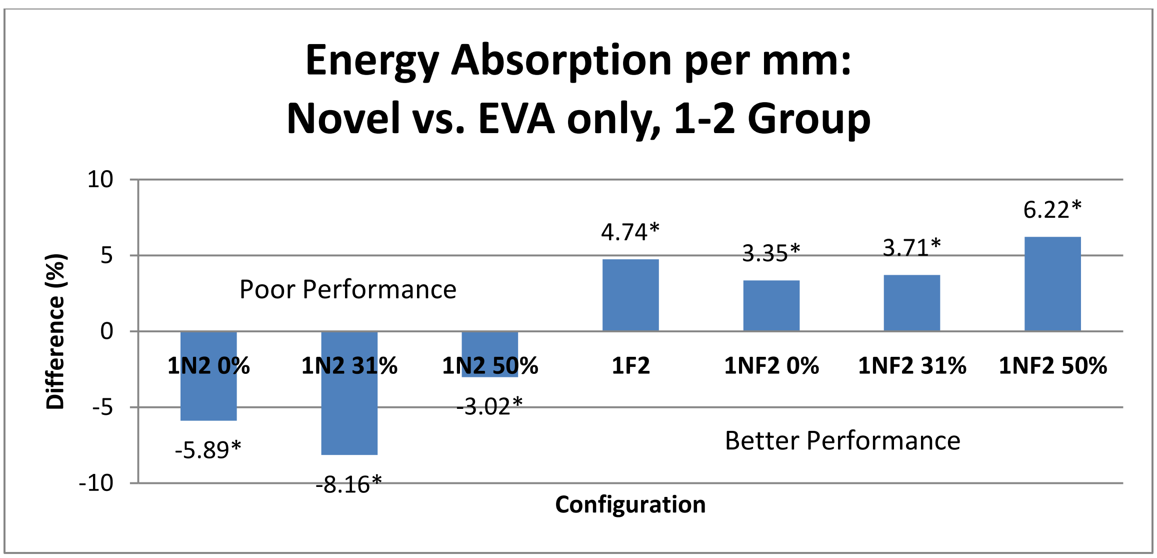


Figure 26. 1-2 Group: percent difference compared to calculated control

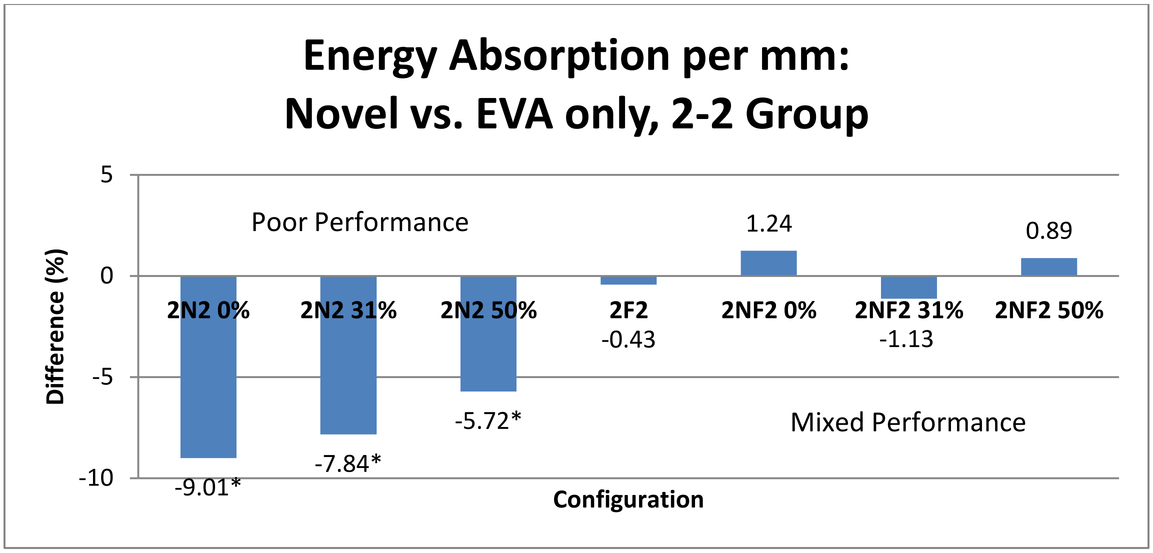


Figure 27. 2-2 Group: percent difference compared to calculated control

Using the curve fit data, a confidence interval of ±95% was calculated. Figure 28 shows the different configurations grouped based on intermediate layer. Percent absorption per millimeter was plotted against thickness. Therefore, the higher the percent absorption per millimeter the better the configuration performed. The confidence intervals are displayed by the dotted curves and sample means found outside of the curves were statistically significant. The data can also be found in Tables 9-11.

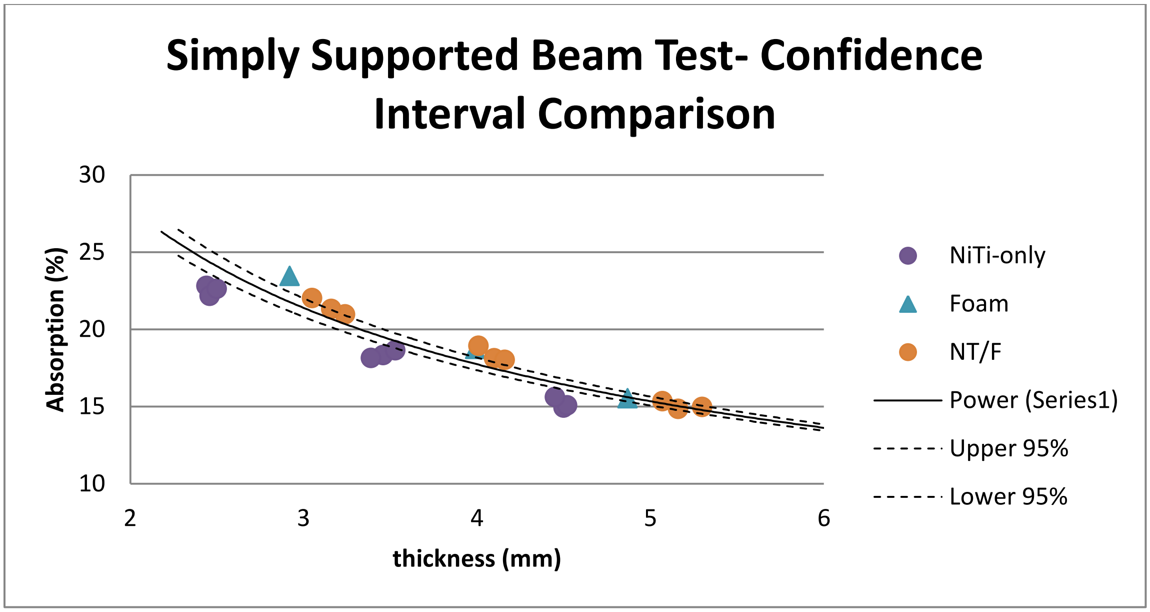


Figure 28. Confidence interval comparison in simply supported beam test

Table 9.

95% Confidence Interval for 1-1 Group in Simply Supported Beam Test

Simply Supported Beam- Confidence Interval Comparison: 1-1 Group				
config 1-1	**thickness**	**%abs/mm**	**-95%**	**95%**
1N1 0%	2.44	22.81*	23.73	25.27
1N1 31%	2.46	22.17*	23.59	25.12
1N1 50%	2.50	22.63*	23.38	24.88
1F1	2.92	23.45*	21.15	22.38
1NF1 0%	3.24	20.97*	19.83	20.91
1NF1 31%	3.16	21.32*	20.14	21.25
1NF1 50%	3.05	22.01*	20.60	21.77

Table 10.

95% Confidence Interval for 1-2 Group in Simply Supported Beam Test

Simply Supported Beam- Confidence Interval Comparison: 1-2 Group				
config 1-2	thickness	%abs/mm	-95%	95%
1N2 0%	3.46	18.33*	19.03	20.02
1N2 31%	3.39	18.13*	19.27	20.28
1N2 50%	3.53	18.64*	18.79	19.75
1F2	3.99	18.71*	17.38	18.19
1NF2 0%	4.11	18.12*	17.06	17.83
1NF2 31%	4.16	18.02*	16.93	17.68
1NF2 50%	4.01	18.93*	17.31	18.12

Table 11.

95% Confidence Interval for 2-2 Group in Simply Supported Beam Test

Simply Supported Beam- Confidence Interval Comparison: 2-2 Group				
config 2-2	thickness	%abs/mm	-95%	95%
2N2 0%	4.50	14.92*	16.10	16.78
2N2 31%	4.52	15.08*	16.06	16.73
2N2 50%	4.45	15.6*	16.22	16.90
2F2	4.87	15.53	15.32	15.92
2NF2 0%	5.30	14.96	14.52	15.04
2NF2 31%	5.16	14.84	14.77	15.31
2NF2 50%	5.07	15.34	14.93	15.49

Similar to the flat plate testing, the NiTi-only configurations in all thickness groups tested below the lower limit of the 95% confidence interval (Tables 9-11). That is, the NiTi-only samples absorbed significantly less energy per mm than the calculated EVA control of the same thickness. The foam-only configurations also tested as in the flat plate method. The 1F1 and 1F2 samples absorbed significantly more energy per mm at 23.45%/mm (95% CI [21.15, 22.38]) and 18.71%/mm (95% CI [17.38, 18.19]), respectively. The 2F2 configuration did not show a difference from the control with 15.53% absorption per mm, 95% CI [15.32, 15.92]). A main difference in the results from the flat plate method was the results for the NiTi/Foam configurations. The 1NF1 and 1NF2 configurations absorbed significantly more energy per mm than the calculated control (Tables 3-4). The 2NF2 configurations all tested within the 95% confidence interval range and were not considered significantly different from the controls (Table 5). Once again, an ANOVA analysis was done for samples containing NiTi to find if there was a difference between the 3 types of porosities within each thickness group. The full results of the ANOVA analysis can be found in appendix E. The results are summarized in Table 6. All *P*-values were above 0.05 therefore, no difference was found between the porosities. This was similar to the results found in the flat plate test. The varying of stiffness by the different porosities did not play a role in shock absorption

Table 12.

ANOVA Comparison of Porosities in Simply Supported Beam Test

Summary of ANOVA comparison to control			
config	F	P-value	F-critical
1N1-0%, 31%, 50%	0.96	0.40	3.35
1N2-0%, 31%, 50%	1.43	0.26	3.35
2N2-0%, 31%, 50%	2.66	0.09	3.35
1NF1-0%, 31%, 50%	1.91	0.17	3.35
1NF2-0%, 31%, 50%	1.66	0.21	3.35
2NF2-0%, 31%, 50%	1.67	0.21	3.35

An ANOVA analysis was also done for the simply supported beam test data in order to confirm our results. This was done similar to the flat plate method. Each configuration was compared to a control sample with the closest thickness. The full results of the ANOVA analysis can be found in Appendix F. Tables 7-9 show the summary of the results.

Table 13.

Summary of 1-1 Group ANOVA Comparison to 1-2 Control

Summary of 1-1 Group ANOVA Comparison to 1-2 Control			
config	**F**	**P-value**	**F-critical**
1N1 0%	70.79	1.19E-7*	4.41
1N1 31%	54.46	7.58E-7*	4.41
1N1 50%	36.32	0.00001*	4.41
1F1	39.60	6.22E-6*	4.41
1NF1 0%	7.39	0.01*	4.41
1NF1 31%	7.28	0.01*	4.41
1NF1 50%	19.19	0.0004*	4.41

Table 14.

Summary of 1-2 Group ANOVA Comparison to 2-2 Control

Summary of 1-2 Group ANOVA Comparison to 2-2 Control			
config	**F**	**P-value**	**F-critical**
1N2 0%	71.87	1.06E-7*	4.41
1N2 31%	53.30	8.79E-7*	4.41
1N2 50%	47.63	0.000002*	4.41
1F2	48.98	0.000002*	4.41
1NF2 0%	10.20	0.005*	4.41
1NF2 31%	9.45	0.007*	4.41
1NF2 50%	37.95	0.00001*	4.41

Table 15.

Summary of 2-2 Group ANOVA Comparison to 2-3 Control

Summary of 2-2 Group ANOVA comparison to 2-3 control			
config	**F**	**P-value**	**F-critical**
2N2 0%	15.60	0.001*	4.41
2N2 31%	8.97	0.008*	4.41
2N2 50%	0.28	0.60	4.41
2F2	4.40	0.05	4.41
2NF2 0%	14.80	0.001*	4.41
2NF2 31%	26.00	0.0001*	4.41
2NF2 50%	6.13	0.02*	4.41

Similar to the flat plate testing results, the NiTi-only configurations performed significantly different when compared to the respective EVA-only control ($P<.05$). There was one exception, the 2N2 50% did not show a difference from the 2-3 control (P=0.6). The foam-only group had a statistically significant difference in the 1-1 and 1-2 groups but was not statistically significant in the 2-2 group (Table 7-9). These results were comparable to the results for the confidence interval analysis. The NiTi/Foam configurations were statistically significant in all three thickness groups with *P*-values below 0.05. This differed from the flat plate test as the NiTi/Foam configurations in the 2-2 group were not found to be statistically significant.

As was the case with the ANOVA results for the flat plate method, the thickness was only approximated and could not truly be normalized. The percent difference in thickness found in the tables in appendix C should be kept in mind when reading the results of the ANOVA analysis.

Chapter 5: Discussion and Conclusion

The goals of this study were to elucidate on the effect a NiTi intermediate layer has on the shock absorptive capacity of a mouthguard. The initial idea was the stiffer NiTi layer would distribute the force better than the EVA due to its stiffness while retaining its shape. A softer foam intermediate layer was also tested. The softer layer has tested well in the literature and absorbs energy by compressing and recovering better than EVA. The testing configurations with both a NiTi strip and foam intermediate layer were expected to surpass the shock absorptive capabilities of any configuration with either intermediate layer component alone by taking advantage of both forms of energy dissipation.

The aforementioned expectations are not what were found in this study. Using a traditional drop tower method, the NiTi-only configurations offered significantly less shock absorption when compared to an EVA-only control. This does not necessarily mean that it is detrimental to the overall protection a hard insert design can offer. Although more impact force was transmitted, further research will be needed to quantify the area that the force is distributed across. No trend was observed as the thickness increased among the three groups although it did follow the EVA-only curve. The analysis using a confidence interval and ANOVA are in agreement and support the significant decrease in shock absorption. The results were similar to those of a study investigating the effects of a hard insert (Westerman 2002). In the study, they concluded that a hard insert reduces the shock absorption capability of a mouthguard but did not explore force distribution. In addition, the study did not take into account any deflection that may be experienced by the maxillofacial complex and only looked at compression as a form of force dissipation. Therefore, adding an incompressible component to the testing sample would hinder energy absorption.

It was a surprise to get the same results in the simply supported beam testing method. The idea behind the testing design was to allow for some deflection to occur and therefore, introducing an added form of energy dissipation. The NiTi-only configurations absorbed significantly less force per millimeter than the control samples. In this case, force distribution did not play the role that was expected.

The NiTi/foam configurations performed similar to the control in the flat plate testing method except in the 2-2 thickness group. The foam seemed to counteract the negative effects of the NiTi layer in the thinner thickness groups. This compensation is lost as the samples get thicker. On the other hand, the same NiTi/foam configuration samples performed better than the control in two of the three thickness groups in the simply supported beam method. . The increase in absorption was not great but it was statistically significant. The effect peaked in the 1-2 thickness group and began to resemble the control in the thicker group. The gain in energy absorption could be due to the way the intermediate components were layered. The NiTi strip was placed facial to the foam. This was done to allow more deformation of the NiTi strip into the foam layer. The added deformation of the test design seemed to have a positive effect on the energy absorption of the samples.

The foam intermediate layer mouthguard has proven to be one of the most shock absorbent designs in the literature (Knapik 2007). It performed as expected in the traditional drop tower testing method. The improved shock absorbency tapered as the thickness of the samples increased. The increase in energy absorption was statistically significant in the thinner groups but was indistinguishable from the control in the 2-2 thickness group. In the simply supported beam test, the foam samples behaved much like the NiTi/foam samples.

It was interesting to see that as the thickness of the samples increased the more their shock absorptive capabilities resembled the control. This finding is in agreement with a study which found that after 4mm of thickness, any gains in protection were only minimal (Westerman, 2000). Indeed, our findings show that the trend is not linear and gains in shock absorption begin to plateau around the same 4mm thickness mark. The aforementioned study tested EVA-only samples while this study tested EVA with intermediate layers. The plateau effect observed in this study is likely due to the increase ratio of EVA to intermediate layer as thickness of samples increase.

Overall, one of the two novel designs performed just as well as foam in the simply supported beam method. As mentioned previously, foam has been one of the most effective intermediate layers tested in previous studies. The improvement was only marginal and only in the thinner samples but it was statistically significant.

Limitations of the Study

In this study, the manufacturing and testing had to be done multiple times due to the amount of NiTi strips. The cost of the NiTi sheets and the laser cutting were very expensive and only 9 strips per porosity design were manufactured. This introduced various sources of error. One of the main sources of error was due to the multiple rounds of testing. The drop tower had to be set up at every round and calibrated. This became significant as friction could have varied from setup to setup. Friction was potentially introduced between the crossheads and the guide rods leading to a decrease in impact force. Also, the height of the impactor potentially varied by .5mm during different rounds of testing. This amounts to about .021J of potential energy and may not be significant. Finally, variations in the sensors may have been accentuated by the multiple rounds of testing.

An obstacle that was not expected was the fracture of some NiTi strips. A few of the 50% porosity NiTi strips fractured at the point of impact. The issue was observed when it happened and new samples were created and tested. The 50% porosity may have made the NiTi strip too weak to support the repeated impacts. The fracturing of the strips required more rounds of testing and therefore, introducing more potential for error.

Recommendations for Further Research

The simply supported beam is a testing method that offers a more complete picture. Other studies should use or improve on this design. One improvement may be an attempt at replicating the deflection experienced by the dentoalveolar complex. Further research involving a hard insert should attempt to quantify the area to which the impact force is distributed. A possible method could be using multiple strain gauges spread over the sample's testing area.

Foams and sponges come in a wide array of designs that can be tailored to the function of a mouthguard. Further research could concentrate on optimizing the composition and design of a foam.

Future research should also focus on a more realistic impact object. One study tested shock absorption using multiple impact objects found in common sports like a hockey puck and a bat (Taekeda 2004). We attempted to test a baseball as the impactor but did not see a difference between the different configurations. It seems most of the energy might have been absorbed by the baseball itself. Testing was discontinued early due to the non-differential results. Future studies may focus on varying the energy in which the baseball or other sport object strikes the sample.

Appendix A

ANOVA for Difference in Porosities- Flat Plate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1N1 0%	10	42397.5	4239.75	103889.398
1N1 31%	10	44061.09	4406.109	7033.0815
1N1 50%	10	42391.67	4239.167	91650.1643

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	185151	2	92575.48	1.37099677	0.270966	3.3541308
Within Groups	1823154	27	67524.21			
Total	2008305	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1N2 0%	10	34239.42	3423.942	46115.75
1N2 31%	10	36092.85	3609.285	34252.11
1N2 50%	10	31555.62	3155.562	105308.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1040815	2	520407.4	8.408313	0.00145	3.354131
Within Groups	1671084	27	61892.01			
Total	2711899	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2N2 0%	10	28981.71	2898.171	19155.84
2N2 31%	10	29144.69	2914.469	30543.45
2N2 50%	10	27755.47	2775.547	63669.95

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	115338.6	2	57669.32	1.526057	0.235558	3.354131
Within Groups	1020323	27	37789.75			
Total	1135662	29				

Anova: Single
Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1NF1 0%	10	29328.58	2932.858	63171.9958
1NF1 31%	10	29708.15	2970.815	57468.7506
1NF1 50%	10	30826.16	3082.616	188836.36

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	121225.5	2	60612.76	0.58756618	0.562627	3.3541308
Within Groups	2785294	27	103159			
Total	2906519	29				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
1NF2 0%	10	24405.91	2440.591	8134.955
1NF2 31%	10	24139.02	2413.902	8902.4
1NF2 50%	10	24423.71	2442.371	22846.97

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5086.517	2	2543.258	0.191298	0.826996	3.354131
Within Groups	358959	27	13294.78			
Total	364045.5	29				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2NF2 0%	10	19919.12	1991.912	10451.54
2NF2 31%	10	21090.43	2109.043	18295.66
2NF2 50%	10	21413.77	2141.377	31534.53

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	123683.1	2	61841.57	3.077628	0.062511	3.354131
Within Groups	542535.6	27	20093.91			
Total	666218.7	29				

Appendix B

ANOVA for Flat Plate Test

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1N1 0%	10	42397.5	4239.75	103889.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8423851	1	8423851	109.6789	4.37E-09	4.413873
Within Groups	1382485	18	76804.7			
Total	9806336	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1N1 31%	10	44061.09	4406.109	7033.081

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10721546	1	10721546	377.8313	1.57E-13	4.413873
Within Groups	510777.7	18	28376.54			
Total	11232324	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1N1 50%	10	42391.67	4239.167	91650.16

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8416286	1	8416286	119.0674	2.29E-09	4.413873
Within Groups	1272331	18	70685.08			
Total	9688617	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1F1	10	30752.01	3075.201	14069.41

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	89028.5	1	89028.5	2.791325	0.112072	4.413873
Within Groups	574104.7	18	31894.71			
Total	663133.2	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1NF1 0%	10	29328.58	2932.858	63172

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	396.4951	1	396.4951	0.007024	0.934132	4.413873
Within Groups	1016028	18	56446			
Total	1016424	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1NF1 31%	10	29708.15	2970.815	57468.75

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4220.094	1	4220.094	0.078741	0.78221	4.413873
Within Groups	964698.7	18	53594.37			
Total	968918.8	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 Con	10	29417.63	2941.763	49720
1NF1 50%	10	30826.16	3082.616	188836.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	99197.84	1	99197.84	0.831651	0.373848	4.413873
Within Groups	2147007	18	119278.2			
Total	2246205	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1N2 0%	10	34239.42	3423.942	46115.75

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5720777	1	5720777	216.6288	1.77E-11	4.413873
Within Groups	475347.6	18	26408.2			
Total	6196125	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1N2 31%	10	36092.85	3609.285	34252.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7875062	1	7875062	384.5926	1.35E-13	4.413873
Within Groups	368574.8	18	20476.38			
Total	8243637	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1N2 50%	10	31555.62	3155.562	105308.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3210184	1	3210184	57.32021	5.32E-07	4.413873
Within Groups	1008079	18	56004.4			
Total	4218263	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1F1	10	23658.62	2365.862	18765.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	669.5559	1	669.5559	0.052585	0.82121	4.413873
Within Groups	229191.8	18	12732.88			
Total	229861.4	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1NF2 0%	10	24405.91	2440.591	8134.955

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	37239.31	1	37239.31	5.020263	0.037904	4.413873
Within Groups	133520.4	18	7417.801			
Total	170759.7	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1NF2 31%	10	24139.02	2413.902	8902.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17767.95	1	17767.95	2.277498	0.148617	4.413873
Within Groups	140427.4	18	7801.523			
Total	158195.4	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-2 Con	10	23542.9	2354.29	6700.647
1NF2 50%	10	24423.71	2442.371	22846.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	38791.31	1	38791.31	2.625681	0.122534	4.413873
Within Groups	265928.6	18	14773.81			
Total	304719.9	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 Con	10	19625.59	1962.559	8010.189
2N2 0%	10	28981.71	2898.171	19155.84

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4376849	1	4376849	322.2295	6.17E-13	4.413873
Within Groups	244494.3	18	13583.02			
Total	4621343	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 Con	10	19625.59	1962.559	8010.189
2N2 31%	10	29144.69	2914.469	30543.45

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4530663	1	4530663	235.0317	8.94E-12	4.413873
Within Groups	346982.7	18	19276.82			
Total	4877646	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 Con	10	19625.59	1962.559	8010.189
2N2 50%	10	27755.47	2775.547	63669.95

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3304747	1	3304747	92.20817	1.66E-08	4.413873
Within Groups	645121.3	18	35840.07			
Total	3949869	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 Con	10	19625.59	1962.559	8010.189
1F1	10	21040.08	2104.008	11234.27

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	100039.1	1	100039.1	10.39667	0.004703	4.413873
Within Groups	173200.1	18	9622.229			
Total	273239.2	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-3 Con	10	19625.59	1962.559	8010.189
2NF2 0%	10	19919.12	1991.912	10451.54

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4307.993	1	4307.993	0.466694	0.503211	4.413873
Within Groups	166155.6	18	9230.867			
Total	170463.6	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-3 Con	10	19625.59	1962.559	8010.189
2NF2 31%	10	21090.43	2109.043	18295.66

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	107287.8	1	107287.8	8.156956	0.010494	4.413873
Within Groups	236752.6	18	13152.92			
Total	344040.4	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 Con	10	19625.59	1962.559	8010.189
2NF2 50%	10	21413.77	2141.377	31534.53

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	159879.4	1	159879.4	8.086005	0.010779	4.413873
Within Groups	355902.5	18	19772.36			
Total	515781.8	19				

Appendix C
Percent Difference in Thickness

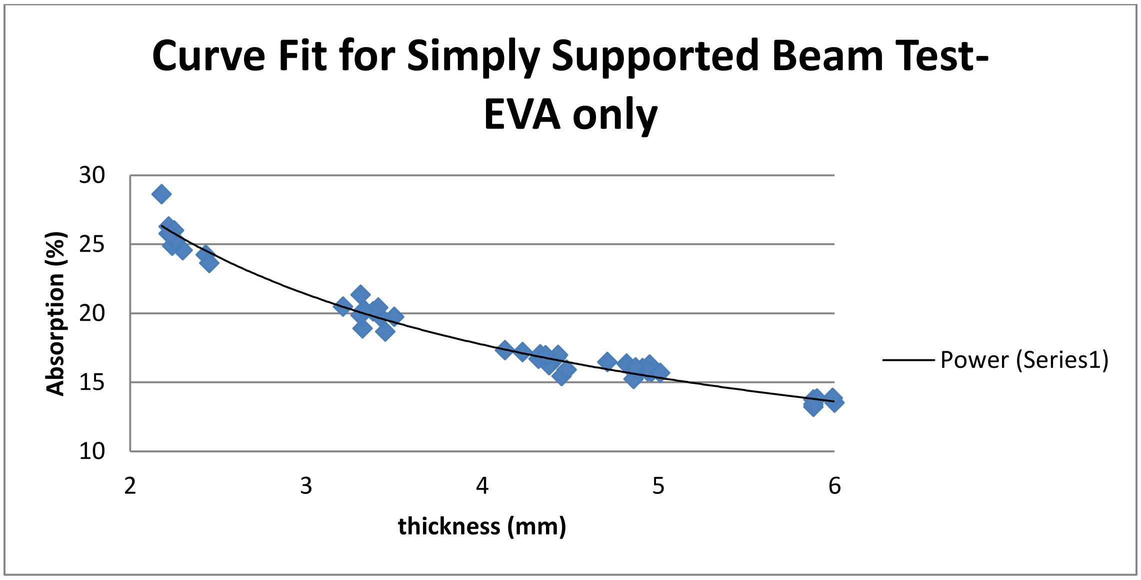
configuration	thickness	% diff
1-2 Con	3.36	0.00
1N1 0%	2.44	27.47
1N1 31%	2.46	26.82
1N1 50%	2.50	25.74
1F1	2.92	13.01
1NF1 0%	3.24	3.69
1NF1 31%	3.16	5.98
1NF1 50%	3.05	9.32

configuration	thickness	% diff
2-2 Con	4.35	0.00
1N2 0%	3.46	20.57
1N2 31%	3.39	22.14
1N2 50%	3.53	18.94
1F2	3.99	21.38
1NF2 0%	4.10	5.77
1NF2 31%	4.16	4.39
1NF2 50%	4.01	7.77

configuration	thickness	% diff
2-3 Con	5.04	0.00
2N2 0%	4.50	10.71
2N2 31%	4.52	10.38
2N2 50%	4.45	11.81
2F2	4.87	3.41
2NF2 0%	5.30	-5.24
2NF2 31%	5.16	2.75
2NF2 50%	5.07	-0.62

Appendix D

Curve Fit Graph for Simply Supported Beam Test



Appendix E

ANOVA for Difference in Porosities-Simply Supported Beam

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1N1 0%	10	2.98630905	0.2986309	0.000153
1N1 31%	10	2.9009566	0.2900956	0.000109
1N1 50%	10	2.95857417	0.2958574	0.000332

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00037913	2	0.000189	0.958604	0.396096	3.354131
Within Groups	0.00533935	27	0.000197			
Total	0.00571849	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1N2 0%	10	2.34921	0.234921	2.85E-05
1N2 31%	10	2.3272	0.23272	4.01E-05
1N2 50%	10	2.3862221	0.23862221	0.000118

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00017793	2	8.89657E-05	1.431172	0.256589	3.354131
Within Groups	0.0016784	27	6.21628E-05			
Total	0.00185633	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2N2 0%	10	1.87056	0.187056	4.86E-05
2N2 31%	10	1.88948	0.188948	6.28E-05
2N2 50%	10	1.9582983	0.19582983	0.000129

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0004264	2	0.000213199	2.659245	0.088272	3.354131
Within Groups	0.00216466	27	8.01727E-05			
Total	0.00259106	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Varia*

				nce
1NF1 0%	10	2.70007	0.270007	0.000157
1NF1 31%	10	2.75036	0.275036	0.000387
1NF1 50%	10	2.846207	0.284621	0.00032

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001102	2	0.000551	1.912221	0.167234	3.354131
Within Groups	0.007783	27	0.000288			
Total	0.008885	29				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1NF2 0%	10	2.29163	0.229163	0.000325
1NF2 31%	10	2.27681	0.227681	0.000296
1NF2 50%	10	2.399007	0.239901	0.000184

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000889	2	0.000445	1.658279	0.209282	3.354131

Within Groups	0.007 24	27	0.000268
Total	0.008 13	29	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2NF2 0%	10	1.84353	0.184353	9.74 E-05
2NF2 31%	10	1.83386	0.183386	5.42 E-05
2NF2 50%	10	1.899717	0.189972	7.61 E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000 253	2	0.000126	1.66 623	0.207806	3.3541 31
Within Groups	0.002 049	27	7.59E-05			
Total	0.002 302	29				

Appendix F

ANOVA for Simply Supported Beam Test

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56	0.256157	0.000102
1N1 0%	10	2.986	0.298630905	0.000153

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00902016	1	0.009020163	70.78615	1.187E-07	4.4138
Within Groups	0.00229371	18	0.000127428			
Total	0.01131387	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56	0.256157	0.000102
1N1 31%	10	2.900	0.2900957	0.000109

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00575917	1	0.00575917	54.4609	7.5836E-07	4.4138
Within Groups	0.001903479	18	0.000105749			
Total	0.007662656	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56157	0.256157	0.000102
1N1 50%	10	2.958574	0.2958574	0.000332

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007880609	1	0.007880609	36.32439	1.0665E-05	4.413873405
Within Groups	0.003905116	18	0.000216951			
Total	0.011785725	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56157	0.256157	0.000102
1F1	10	3.03943	0.303943	0.000474

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01141750	1	0.01141750	39.5965	6.2247E-06	4.41387340
Within Groups	0.00519022	18	0.00028834			
Total	0.01660773	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56157	0.256157	0.00010

				2
1NF1 0%	10	2.70007	0.270007	0.000157

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00095911	1	0.00095911	7.38511	0.0141150	4.4138
Within Groups	0.00233768	18	0.00012987			
Total	0.00329679	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56157	0.256157	0.00010
1NF1 31%	10	2.75036	0.275036	0.00038

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00178208	1	0.00178208	7.27776	0.0147223	4.4138
Within Groups	0.00440760	18	0.00024486			
Total	0.006189684	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1-2 con	10	2.56157	0.256157	0.000102
1NF1 50%	10	2.8462067	0.28462067	0.00032

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004050903	1	0.004050903	19.18659	0.00036089	4.413873405
Within Groups	0.003800376	18	0.000211132			
Total	0.00785127	19				

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Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1N2 0%	10	2.34921	0.234921	2.85E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.003289	1	0.003289	71.86609	1.06E-07	4.413873
Within Groups	0.000824	18	4.58E-05			
Total	0.004112	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1N2 31%	10	2.3272	0.23272	4.01E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002748	1	0.002748	53.30132	8.79E-07	4.413873
Within Groups	0.000928	18	5.16E-05			
Total	0.003676	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05

1N2 50%	10	2.386222	0.238622	0.000118

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.004306	1	0.004306	47.63417	1.88E-06	4.413873
Within Groups	0.001627	18	9.04E-05			
Total	0.005934	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1F2	10	2.37155	0.237155	9.57E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.003886	1	0.003886	48.97878	1.56E-06	4.413873
Within Groups	0.001428	18	7.94E-05			
Total	0.005315	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1NF2 0%	10	2.29163	0.229163	0.000325

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001978	1	0.001978	10.20358	0.005025	4.413873
Within Groups	0.003489	18	0.000194			

Total	0.005466	19

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1NF2 31%	10	2.27681	0.227681	0.000296

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001694	1	0.001694	9.445376	0.00655	4.413873
Within Groups	0.003228	18	0.000179			
Total	0.004922	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-2 con	10	2.09275	0.209275	6.3E-05
1NF2 50%	10	2.399007	0.239901	0.000184

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00469	1	0.00469	37.95136	8.13E-06	4.413873
Within Groups	0.002224	18	0.000124			
Total	0.006914	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-3 con	10	1.979266	0.197927	2.71E-05
2N2 0%	10	1.87056	0.187056	4.86E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000591	1	0.000591	15.60399	0.000938	4.413873
Within Groups	0.000682	18	3.79E-05			
Total	0.001272	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-3 con	10	1.979266	0.197927	2.71E-05
2N2 31%	10	1.88948	0.188948	6.28E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000403	1	0.000403	8.969423	0.007771	4.413873
Within Groups	0.000809	18	4.49E-05			
Total	0.001212	19				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2-3 con	10	1.979266	0.197927	2.71E-05
2N2 50%	10	1.958298	0.19583	0.000129

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	2.2E-05	1	2.2E-05	0.281535	0.602183	4.413873
Within Groups	0.001405	18	7.81E-05			
Total	0.001427	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 con	10	1.979266	0.197927	2.71E-05
2F2	10	1.931465	0.193146	2.48E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000114	1	0.000114	4.402978	0.050255	4.413873
Within Groups	0.000467	18	2.59E-05			
Total	0.000581	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 con	10	1.979266	0.197927	2.71E-05
2NF2 0%	10	1.84353	0.184353	9.74E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000921	1	0.000921	14.80331	0.00118	4.413873
Within Groups	0.00112	18	6.22E-05			
Total	0.002041	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 con	10	1.979266	0.197927	2.71E-05
2NF2 31%	10	1.83386	0.183386	5.42E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001057	1	0.001057	25.99727	7.5E-05	4.413873
Within Groups	0.000732	18	4.07E-05			
Total	0.001789	19				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
2-3 con	10	1.979266	0.197927	2.71E-05
2NF2 50%	10	1.899717	0.189972	7.61E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000316	1	0.000316	6.134964	0.023404	4.413873
Within Groups	0.000928	18	5.16E-05			
Total	0.001245	19				

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